FILE COPY

2121

ASSESSMENT OF FACTORS AFFECTING THE PERFORMANCE OF ONTARIO SEWAGE TREATMENT FACILITIES

Technical Report

NOVEMBER 1992

Canadä Ontario

10/11/92

ISBN 0-7778-0097-7

ASSESSMENT OF FACTORS AFFECTING THE PERFORMANCE OF ONTARIO SEWAGE TREATMENT FACILITIES

NOVEMBER 1992

Cette publication technique
n'est disponible qu'en anglais.

Copyright: Queen's Printer for Ontario, 1992
This publication may be reproduced for non-commercial purposes
with appropriate attribution.

Log 92-2307-032
PIBS 2121

ASSESSMENT OF FACTORS AFFECTING THE PERFORMANCE OF ONTARIO SEWAGE TREATMENT FACILITIES

Report prepared for:

Ontario Ministry of the Environment
Environment Canada
and
The Municipal Engineers Association

Report prepared by:

XCG CONSULTANTS LIMITED
Kitchener, Ontario

NOVEMBER 1992

Log 92-2307-032
PIBS 2121

ACKNOWLEDGEMENTS

We would like to acknowledge the assistance provided by the following individuals during the course of the study:

1. Members of the Technical Steering Committee:

   Dr. D. Chapman, Co-Chairman, Wastewater Technology Centre
   Mr. G. Wheeler, Co-Chairman, MOE
   Mr. T. Ho, Water Resources Branch, MOE
   Mr. M. Auger, Southwestern Region, MOE
   Mr. M. Beland, Southeastern Region, MOE
   Mr. W. Coulter, City of Chatham, representing the Municipal Engineers Association
   Mr. G. McKenna, City of Cornwall, representing the Municipal Engineers Association
   Mr. A. Wollin, Ontario Region, Environment Canada

2. Superintendents and staff at the twelve Water Pollution Control Plants who willingly cooperated and provided information during the study.

3. The municipalities that provided process study reports analyzed as part of the investigation.

Funding for the project was provided by Environment Canada and the Ontario Ministry of the Environment.

DISCLAIMER

This report was prepared for the Ontario Ministry of the Environment and Environment Canada as part of a cooperative project. The views and ideas expressed in this report are those of the author and do not necessarily reflect the views and policies of the Ministry of the Environment or Environment Canada, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

Any person who wished to republish part or all of this report should apply for permission to do so to the Water Resources Branch, Ontario Ministry of the Environment, 135 St. Clair Avenue West, Toronto, Ontario, M4V 1P5, Canada.

EXECUTIVE SUMMARY

In May of 1991, the Ontario Ministry of the Environment and Environment Canada in cooperation with the Municipal Engineers Association initiated an investigation with the overall objective of identifying factors which contribute to poor performance at Ontario municipal sewage treatment plants (STPs). The project comprised two parallel project stages, termed Study 1 and Study 2. Study 1 was further sub-divided into two components, Phase 1 and Phase 2.

The overall objective of Study 1 - Phase 1 was to identify the principal factors limiting the performance of Ontario STPs and to recommend optimization approaches to address these performance limiting factors. Study 1 - Phase 2 will demonstrate the effectiveness of selected optimization approaches recommended in Phase 1. Study 2 was designed to evaluate the U.S. EPA's Composite Correction Program as a tool for diagnosing and subsequently improving the performance of Ontario STPs. This report presents the findings of Study 1 - Phase 1.

SCOPE OF STUDY 1 - PHASE 1

Based on an analysis of the historical database for municipal sewage treatment plants in Ontario, it was concluded that extended aeration plants should be able to achieve monthly average BOD and TSS concentrations of 15 mg/l and 20 mg/l, whereas other conventional secondary plants should be able to achieve monthly average BOD and TSS concentrations of 25 mg/l and 25 mg/l, respectively.

Twelve STPs with a history of performance problems related to their ability to achieve the aforementioned monthly BOD_5 and TSS objectives were subjected to extensive evaluation to identify the causes of poor performance. To support this analysis, the findings of detailed process studies conducted at seven other STPs were reviewed and integrated with the results from the 12 STPs. In addition, analysis of the effects of limiting raw sewage bypass and the costs of achieving nitrification was undertaken.

FACTORS AFFECTING STP PERFORMANCE

The most frequently encountered and most important factors identified as limiting the performance of Ontario STPs were:

- Inadequate sludge wastage and disposal.
- A general lack of understanding of the fundamentals of sewage treatment processes and the inadequate application of these concepts to process control.
- Policies of the plant administration and lack of support provided to plant operational staff.
- Excessive hydraulic loading.
- Inadequate instrumentation and control.
- Extraneous flow due to infiltration and inflow into the sewage collection system.

- Inadequate process monitoring to support process control decisions.
- Inadequate oxygen transfer capacity to meet oxygen demand.
- Industrial discharges to the STP.
- Inadequate O&M manuals.

These findings concur with the conclusions of similar studies undertaken in the United States in the late 1970's.

There was a unique combination of design, operational and administrative factors which contributed to poor performance at any specific plant. Equipment maintenance was not identified as a factor affecting performance. In order to achieve long-term performance improvements, all of the factors which contribute to poor performance at a facility must be addressed.

BENEFITS AND COSTS OF STP OPTIMIZATION

It was concluded that performance improvements could be achieved at ten of the 12 STPs studied through modifications to operating strategies and minor physical plant changes. More significant upgrading would be required at the other two STPs. It was projected that, as a result of these changes, an overall reduction of 30 percent in the BOD_5 and 46 percent in the TSS loading discharged from these 12 facilities was attainable. The estimated costs of the physical changes at these 12 STPs was approximately $4,700,000. About two-thirds of this cost would be incurred at the two STPs where significant upgrading was needed. Province-wide, this suggests an order of magnitude cost of $100 million to optimize the operation of municipal secondary STPs to comply with monthly BOD_5 and TSS effluent guidelines.

This cost does not include any costs of upgrading operator process control skills through improved training practices, increased enforcement activities to provide an incentive to optimize performance or changes to administrative or policy factors currently limiting plant performance. **All of these factors must be addressed before long-term improvements can be made at STPs with performance problems.**

EFFECT OF LIMITING BYPASS AND REQUIRING NITRIFICATION ON STP COMPLIANCE

Based on the limited data available, it was concluded that limiting raw sewage bypass would not affect the performance of six of the 12 STPs evaluated during this study. The performance of the other six facilities would be affected but the extent of the impact could not be estimated due to the lack of information regarding the frequency, duration and magnitude of bypass events at these plants.

Ten of the 12 STPs evaluated should be capable of achieving effluent nitrogen limits of 8 mg/L NH_3-N and/or 10 mg/L TKN without significant capital cost upgrading. If the costs of upgrading these 12 STPs to meet these limits are representative of the costs at other secondary treatment facilities in Ontario, the order-of-magnitude costs of achieving this effluent nitrogen limit province-wide in such facilities were estimated at $100 million.

When more stringent effluent nitrogen limits of 3 mg/L NH_3-N and/or 5 mg/L TKN are imposed, seven of the 12 STPs should be capable of achieving this performance without major capital cost upgrading. Order-of-magnitude costs of achieving this effluent nitrogen limit province-wide in secondary treatment facilities based on extrapolation of costs expected at these 12 STPs were estimated at $860 million.

RECOMMENDATIONS

Specific recommendations to address the factors identified as significant contributors to poor STP performance were developed and are presented in the report.

Selected key recommendations resulting from Study 1 - Phase 1 include:

- The benefits of an integrated STP optimization approach which addresses all of the factors limiting performance should be demonstrated at a representative number of the facilities which were included in this phase of the project.
- Current methods of delivering training to STP operating staff need to be assessed and consideration given to training staff at the facilities which they are responsible for operating.
- Training courses aimed at improving plant management staff's leadership, communication and motivational skills should be developed. Management staff should be encouraged to involve operators in developing site-specific process monitoring programs and operating strategies.
- Programs should be developed to provide municipal STP operators access to technical process specialists where warranted.
- A Best Management Practices Guidance Manual should be developed. The manual should recommend appropriate levels of staffing, instrumentation and process monitoring for various sizes and types of STPs.
- Municipalities and consulting engineers should be encouraged to integrate "NEEDS" and "Environmental Assessment (EA)" studies in managing I/I problems. The integrated approach will allow an optimal combination of sewer rehabilitation, storage and treatment to address extraneous flow problems.
- Adequate sludge storage capacity, adequate approved land for sludge disposal, contingency plans, more expedient approval of disposal fields and improved record-keeping and reporting are needed to address sludge wastage and disposal problems common at Ontario STPs. Regionalization of land utilization programs should be considered where appropriate.
- Certificates of Approval with specific effluent limits should be issued and current enforcement programs enhanced to raise awareness and provide incentive to STP operating authorities to improve plant performance.

- The approaches used in U.S. jurisdictions such as Wisconsin and New York (Appendix 1 and 2) to encourage plant optimization and discourage unnecessary plant expansion should be evaluated and considered for application in Ontario.

SOMMAIRE

En mai 1991, le ministère de l'Environnement de l'Ontario et Environnement Canada, avec le concours de la Municipal Engineers Association, ont entrepris une enquête dont l'objectif global était de déterminer les facteurs qui contribuent à la piètre performance des usines de traitement des égouts des municipalités en Ontario (UTE). Le projet comprenait deux étapes parallèles appelées Étude 1 et Étude 2. L'Étude 1 a été à son tour subdivisée en deux éléments, soit la Phase 1 et la Phase 2.

L'objectif global de l'Étude 1 - Phase 1 était de déterminer les principaux facteurs qui limitent la performance des UTE de l'Ontario et de recommander des approches d'optimisation pour prendre des mesures tenant compte de ces facteurs. L'Étude 1 - Phase 2 prouvera l'efficacité de certaines approches d'optimisation recommandées à la Phase 1. L'Étude 2 a été conçue pour évaluer le Composite Correction Program de l'EPA des É.-U. en tant qu'outil de diagnostic et améliorer par la suite la performance des UTE de l'Ontario. Le présent rapport présente les conclusions de l'Étude 1 - Phase 1.

PORTÉE DE L'ÉTUDE 1 - PHASE 1

D'après une analyse de la base de données historiques sur les usines de traitement des égouts des municipalités en Ontario, on a conclu que des usines d'aération agrandies devraient pouvoir assurer des concentrations DBO et TTF moyennes de 15 mg/L et de 20 mg/L par mois, tandis que les autres usines de traitement secondaire conventionnelles devraient pouvoir assurer des concentrations moyennes DBO et TSS de 25 mg/L et de 25 mg/L par mois, respectivement.

Douze UTE qui ont toujours posé des problèmes pour ce qui est de la capacité d'atteindre les objectifs précités (DBO_5 et TSS) ont été soumises à de longues évaluations, afin qu'on puisse déterminer les causes de leur piètre performance. Pour appuyer cette analyse, on a examiné les conclusions d'études de processus détaillés qui avaient été menées à sept autres UTE et on les a intégrées aux résultats obtenus des 12 UTE. En outre, on a entrepris une analyse des effets de la limitation des dérivations pour les égouts non traités et des coûts de la nitrification.

FACTEURS NUISANT À LA PERFORMANCE DES UTE

On a établi que les facteurs les plus fréquents et les plus importants qui limitaient la performance des UTE de l'Ontario étaient les suivants :

- Une élimination des boues insuffisante.
- Un manque général de compréhension des principes fondamentaux des processus de traitement des égouts et l'application inadéquate de ces concepts aux fins de contrôle des processus.

- Les politiques administratives et le manque de soutien aux employés chargés des opérations.
- La charge hydraulique excessive.
- Les instruments et les contrôles inadéquats.
- Le flux de matières étrangères dû à l'infiltration et à l'entrée dans le réseau de collecte.
- La surveillance des processus insuffisante qui ne peut favoriser la prise de décisions sur le contrôle des processus.
- La capacité de transfert d'oxygène insuffisante par rapport à la demande.
- Les rejets industriels qui sont acheminés à l'UTE.
- Les manuels O&E inadéquats.

Ces conclusions concordent avec celles qui résultent d'études semblables entreprises aux États-Unis à la fin des années 1970.

Une combinaison unique de facteurs se rattachant à la conception, aux opérations et à l'administration contribuait à la piètre performance des usines. L'entretien de l'équipement n'a pas été signalé comme un facteur nuisant à la performance. Pour que des améliorations à long terme soient possibles, tous les facteurs qui contribuent à la piètre performance d'une usine doivent être examinés.

AVANTAGES ET COÛTS DE L'OPTIMISATION - UTE

On a conclu qu'à dix des 12 UTE soumises aux études, des améliorations seraient possibles à condition de modifier les stratégies d'exploitation et d'apporter des changements mineurs aux installations. Des améliorations plus considérables seraient requises aux deux autres UTE. Selon les prévisions, les changements pourraient donner lieu à une réduction globale de 30 % de la DBO_5 et de 46 % de la charge TSS dans ces 12 usines. Le coût estimatif des changements à apporter aux installations des 12 UTE s'élève à environ 4 700 000 $. À peu près les deux tiers de cette somme devraient être consacrés aux deux UTE où d'importantes améliorations sont nécessaires. Cela laisse supposer qu'à l'échelle de la province il faudra prévoir des dépenses de l'ordre de 100 millions de dollars pour optimiser l'exploitation des usines de traitement secondaire aux fins de l'observation des normes relatives aux effluents (concentrations DBO_5 et TSS par mois).

Ce montant n'inclut pas le coût du perfectionnement des opérateurs sur le plan du contrôle des processus par de meilleures méthodes de formation, de l'augmentation de l'application accrue des règlements pour inciter les responsables à optimiser la performance ou des changements relatifs aux facteurs administratifs ou aux politiques qui limitent actuellement la performance des usines. **Il faut prendre des mesures à l'égard de tous ces facteurs si l'on veut améliorer à long terme la performance des UTE qui posent des problèmes.**

EFFET DE LA LIMITATION DES DÉRIVATIONS ET BESOIN DE NITRIFICATION POUR L'OBSERVATION DES NORMES PAR LES UTE

En se basant sur les données limitées disponibles, on a conclu que la limitation des dérivations pour les égouts non traités ne nuirait pas à la performance de six des 12 UTE qui ont été soumises à une évaluation au cours de cette étude. Cela nuirait au rendement des six autres usines, mais il ne serait pas possible d'estimer les répercussions de telles mesures à cause du manque d'information au sujet de la fréquence, de la durée et de l'importance des dérivations à ces usines.

Dix des 12 UTE qui ont été soumises à une évaluation devraient pouvoir respecter les limites établies relatives à l'azote dans les effluents, soit 8 mg/L NH_3-N et (ou) 10 mg/L ATK sans que les améliorations nécessitent des dépenses de capitaux considérables. Si le coût de l'amélioration de ces 12 UTE pour que ces limites puissent être respectées est représentatif du coût de l'amélioration des autres usines de traitement secondaire en Ontario, il faudrait prévoir des dépenses de l'ordre de 100 millions de dollars pour que ces normes soient respectées dans toute la province.

Si l'on imposait des limites plus rigoureuses pour l'azote dans les effluents, soit 3 mg/L NH_3-N et (ou) 5 mg/L ATK, sept des 12 UTE devraient être en mesure de respecter ces normes sans que les améliorations nécessitent des dépenses de capitaux considérables. En extrapolant le montant des dépenses prévues pour ces 12 UTE, on estime à 860 millions de dollars les dépenses nécessaires pour que ces normes soient respectées par les usines de traitement secondaire dans toute la province.

RECOMMANDATIONS

Des recommandations précises sur les mesures à prendre compte tenu des facteurs qui contribuent largement à la piètre performance des UTE ont été élaborées et sont présentées dans ce rapport.

Principales recommandations résultant de l'Étude 1 - Phase 1 :

- Les avantages d'une approche d'optimisation intégrée pour les UTE qui tienne compte de tous les facteurs limitant la performance devraient être démontrés à un nombre représentatif d'usines qui ont été examinées au cours de cette phase du projet.

- Les méthodes actuelles de formation du personnel d'exploitation des UTE doivent être évaluées, et il faudrait envisager la possibilité de former les employés aux usines qu'ils sont chargés de faire fonctionner.

- Il faudrait élaborer des cours de formation visant à accroître les aptitudes en leadership pour la gestion des usines et en communication ainsi qu'à accroître la motivation. Les gestionnaires devraient être encouragés à faire participer les opérateurs à la conception de programmes de surveillance des processus sur le terrain et de stratégies de fonctionnement.

- Il faudrait élaborer des programmes permettant aux opérateurs des UTE municipales de recourir à des spécialistes des processus techniques lorsque cela est justifié.

- Il faudrait rédiger un manuel qui serait un guide sur les meilleures méthodes de gestion. Le manuel devrait recommander des niveaux appropriés de personnel, d'instruments et de surveillance des processus pour les UTE de diverses dimensions et de divers genres.

- Il faudrait encourager les municipalités et les ingénieurs-conseils à intégrer les «NEEDS» et les études d'«évaluation environnementale» (EE) à la gestion de problèmes d'infiltration/flux d'entrée. L'approche intégrée permettra une combinaison optimale de remise en état des collecteurs, de stockage et de traitement des égouts visant à régler les problèmes de flux de matières étrangères.

- Il faut une capacité suffisante de stockage des boues, suffisamment de terrains où l'élimination des boues est autorisée, des plans d'urgence, une approbation plus rapide relative aux champs d'épuration ainsi qu'une meilleure tenue de dossiers et un meilleur système d'établissement de rapports pour régler les problèmes courants d'élimination des boues aux UTE, en Ontario. On devrait envisager la régionalisation des programmes d'utilisation des terrains, au besoin.

- Il faudrait délivrer des certificats d'approbation précisant les limites relatives aux effluents et améliorer les programmes actuels d'application des règlements pour sensibiliser davantage les responsables et encourager les autorités chargées de l'exploitation des UTE à améliorer la performance des usines.

- Les approches auxquelles on a recouru aux É.-U., dans le Wisconsin et dans l'État de New York par exemple (annexes 1 et 2), pour encourager l'optimisation des usines et décourager les agrandissements non nécessaires d'usines devraient être évaluées et examinées aux fins d'application en Ontario.

TABLE OF CONTENTS

ACKNOWLEDGEMENTS i
EXECUTIVE SUMMARY ii
SOMMAIRE vi
TABLE OF CONTENTS x
LIST OF TABLES xii
LIST OF FIGURES xiv

1.0 INTRODUCTION 1
- 1.1 BACKGROUND 1
- 1.2 OBJECTIVES 2
- 1.3 REPORT FORMAT 3

2.0 PROJECT SCOPE AND METHODOLOGY 4
- 2.1 OVERVIEW OF SCOPE OF STUDY 1 - PHASE 1 4
- 2.2 SELECTION OF FACILITIES FOR ASSESSMENT 4
- 2.3 STP PROCESS STUDIES INCLUDED IN STUDY 1 - PHASE 1 8
- 2.4 ASSESSMENT PROCEDURES 10
  - 2.4.1 Site Visits 10
  - 2.4.2 Data Analysis 10
  - 2.4.3 Review of Process Studies 13
- 2.5 FACTORS INCLUDED IN THE ASSESSMENT 13
  - 2.5.1 General 13
  - 2.5.2 Factors Considered in the Design of Liquid Treatment Process Units 14
  - 2.5.3 Factors Considered in the Design of Sludge Management Process Units 15
  - 2.5.4 Operational Factors Considered 16
  - 2.5.5 Maintenance Factors Considered 16
  - 2.5.6 Administrative Factors Considered 17
  - 2.5.7 Summary of Factors Considered 17

3.0 FACTORS CONTRIBUTING TO POOR PERFORMANCE 19
- 3.1 GENERAL 19
- 3.2 FACTORS IDENTIFIED AT VISITED SITES 19
  - 3.2.1 Liquid Treatment Unit Design Factors 25
  - 3.2.2 Sludge Treatment Unit Design Factors 37
  - 3.2.3 Operational Factors 40
  - 3.2.4 Maintenance Factors 42
  - 3.2.5 Administrative Factors 43
- 3.3 FACTORS IDENTIFIED FROM PROCESS STUDY REPORTS 48
  - 3.3.1 Crystal Beach WPCP 48
  - 3.3.2 Belleville WPCP 48
  - 3.3.3 Hespeler WPCP 49
  - 3.3.4 Toronto Highland Creek WPCP 50
  - 3.3.5 Corbett Creek WPCP 51

3.3.7 Burlington Skyway WPCP 52
3.3.8 Summary of Factors Identified in Process Study Reports 53
3.4 SUMMARY OF FACTORS CONTRIBUTING TO POOR PERFORMANCE 59
3.4.1 Comparison of Findings of Site Visits and Process Study Reports 59
3.4.2 Summary of Overall Findings 59
3.4.3 Comparison of Findings with Other STP Assessments 67
3.5 EFFECT OF LIMITING BYPASS AND REQUIRING NITRIFICATION ON STP COMPLIANCE 69
3.5.1 Bypassing Restrictions 69
3.5.2 Nitrification Requirements 72

4.0 APPROACHES TO IMPROVE PERFORMANCE 79
4.1 GENERAL 79
4.2 SLUDGE MANAGEMENT LIMITATIONS 80
4.3 OPERATOR TRAINING 81
4.4 ADMINISTRATIVE SUPPORT 83
4.5 HYDRAULIC LOADING 84
4.6 INDUSTRIAL LOADING 86
4.7 OXYGEN TRANSFER 86
4.8 INSTRUMENTATION AND CONTROL 87
4.9 EFFECTS OF STP OPTIMIZATION 88
4.10 COSTS OF STP OPTIMIZATION 90

5.0 CONCLUSIONS 91
5.1 FACTORS AFFECTING STP PERFORMANCE 91
5.2 BENEFITS AND COSTS OF STP OPTIMIZATION 93
5.3 EFFECTS OF MISA ON STP COMPLIANCE 93

6.0 RECOMMENDATIONS 94
6.1 SLUDGE MANAGEMENT LIMITATIONS 94
6.2 OPERATOR TRAINING 94
6.3 ADMINISTRATIVE SUPPORT 95
6.4 HYDRAULIC LOADING AND EXTRANEOUS FLOW 95
6.5 INDUSTRIAL LOADING 95
6.6 OXYGEN TRANSFER 96
6.7 INSTRUMENTATION AND CONTROL 96
6.8 OTHER RECOMMENDATIONS 96

REFERENCES 97
GLOSSARY 101
APPENDIX 1 STATE OF WISCONSIN'S COMPLIANCE MAINTENANCE PROGRAM
APPENDIX 2 STATE OF NEW YORK'S INTEGRATED COMPLIANCE STRATEGY SYSTEM

LIST OF TABLES

TABLE 1 STPs SELECTED FOR DETAILED ANALYSIS IN STUDY 1 - PHASE 1 6

TABLE 2 PERFORMANCE HISTORY OF STPs SELECTED FOR DETAILED ANALYSIS (1986 - 1990) 7

TABLE 3 STPs FOR WHICH PROCESS STUDY REPORTS WERE REVIEWED 9

TABLE 4 INFORMATION REQUESTED FROM STPs FOR DETAILED ANALYSIS 11

TABLE 5 FACTORS CONSIDERED AS CONTRIBUTING TO PERFORMANCE PROBLEMS 18

TABLE 6 TEN MOST FREQUENTLY IDENTIFIED FACTORS CONTRIBUTING TO POOR PERFORMANCE 22

TABLE 7 TEN HIGHEST RANKED FACTORS ACCORDING TO FREQUENCY RATING 24

TABLE 8 TEN HIGHEST RANKED FACTORS BASED ON IMPORTANCE RATING 27

TABLE 9 SUMMARY OF RANKING OF TEN MOST PREVALENT FACTORS 28

TABLE 10 ULTIMATE SLUDGE DISPOSAL METHOD 38

TABLE 11 SUMMARY OF MOST IMPORTANT FACTORS AFFECTING PERFORMANCE OF STPs SUBJECTED TO PROCESS STUDIES 57

TABLE 12 COMPARISON OF TEN MOST FREQUENTLY IDENTIFIED FACTORS BETWEEN VISITED AND STUDIED FACILITIES 60

TABLE 13 COMPARISON OF TEN MOST IMPORTANT FACTORS AFFECTING PERFORMANCE AT VISITED AND STUDIES PLANTS 61

TABLE 14 TEN MOST FREQUENT AND MOST IMPORTANT FACTORS AFFECTING PERFORMANCE AT ALL FACILITIES 66

TABLE 15 COMPARISON TO OTHER STUDY RESULTS (TEN MOST IMPORTANT PROBLEMS) 68

LIST OF TABLES (cont'd)

TABLE 16 SUMMARY OF BYPASS INFORMATION 70

TABLE 17 EFFECTS OF BYPASS RESTRICTIONS ON STP PERFORMANCE 73

TABLE 18 COMPARISON OF STP PERFORMANCE TO HIGHER NITROGEN LIMIT (LIMIT A) 75

TABLE 19 COMPARISON OF STP PERFORMANCE TO LOWER NITROGEN LIMIT (LIMIT B) 76

TABLE 20 UPGRADING REQUIRED TO ACHIEVE NITRIFICATION LIMITS 77

LIST OF FIGURES

FIGURE 1	FREQUENCY OF OCCURRENCE OF PERFORMANCE LIMITING FACTORS	21
FIGURE 2	FREQUENCY RATING OF PERFORMANCE LIMITING FACTORS	23
FIGURE 3	IMPORTANCE RATING OF FACTORS LIMITING PERFORMANCE	26
FIGURE 4	AVERAGE PEAKING FACTOR	29
FIGURE 5	AVERAGE PER CAPITA WASTEWATER FLOW	30
FIGURE 6	AVERAGE FIVE YEAR FLOW AS PERCENT OF DESIGN FLOW	32
FIGURE 7	COMPARISON OF PUMP STATION OUTPUT TO PLANT DESIGN CAPACITY	33
FIGURE 8	COMPARISON OF AVERAGE ORGANIC LOADING WITH DESIGN ORGANIC LOADING	35
FIGURE 9	COMPARISON OF OXYGEN REQUIREMENTS WITH ESTIMATED TRANSFER CAPACITY	36
FIGURE 10	ESTIMATED SLUDGE STORAGE TIME	39
FIGURE 11	COMPARISON OF ACTUAL AND THEORETICAL SLUDGE GENERATION	41
FIGURE 12	RELATIONSHIP BETWEEN STAFFING AND PLANT DESIGN FLOW	44
FIGURE 13	RELATIONSHIP BETWEEN O & M COSTS AND PLANT THROUGHPUT	46
FIGURE 14	LABOUR AND SLUDGE DISPOSAL COSTS AS A PERCENT OF O & M COSTS	47
FIGURE 15	FREQUENCY OF OCCURRENCE OF PERFORMANCE LIMITING FACTORS FROM PROCESS STUDY REPORTS	54

LIST OF FIGURES (cont'd)

FIGURE 16 FREQUENCY RATING OF PERFORMANCE LIMITING FACTORS FROM PROCESS STUDY REPORTS 55

FIGURE 17 IMPORTANCE RATING OF FACTORS LIMITING PERFORMANCE FROM PROCESS STUDY REPORT 56

FIGURE 18 FREQUENCY OF OCCURRENCE OF PERFORMANCE LIMITING FACTORS AT ALL STPs 63

FIGURE 19 FREQUENCY RATING OF PERFORMANCE LIMITING FACTORS AT ALL STPs 64

FIGURE 20 IMPORTANCE RATING OF FACTORS LIMITING PERFORMANCE AT ALL STPs 65

1.0 INTRODUCTION

1.1 BACKGROUND

In the Report on the 1989 Discharges from Sewage Treatment Plants in Ontario (1), it was identified that 16 of the 364 STPs assessed exceeded effluent guidelines for BOD_5 and 41 STPs exceeded guidelines for TSS when the guidelines were applied on an annual average basis. It was further noted that several STPs had exceeded guidelines for two or even three successive years. Evaluation of these facilities against effluent guidelines applied on the basis of monthly average concentrations, as is the case with guidelines for total phosphorus concentrations, would substantially increase the number of STPs in Ontario which are not in compliance. For example, in 1988, 35 percent of the 108 conventional plants in Ontario would have been out of compliance with a monthly average effluent BOD_5 or TSS guideline at least one month in the year. The percentage of plants not complying at least two months and three months would have been 22 percent and 16 percent, respectively. Furthermore, it is expected that the MISA programme will result in the application of still more stringent requirements on municipal STPs to reduce bypassing and to minimize discharges of ammonia in plant effluents. Such legislation may result in additional compliance difficulties at Ontario municipal STPs.

Similar performance difficulties were identified at municipal STPs in the United States in the 1970's and 1980's. The 1973 and 1974 U.S. EPA Clean Water Reports to Congress showed that about one-third of all treatment facilities constructed with federal grant assistance were not meeting design performance standards. As a result of that finding, a three and one-half year study, referred to as the East-West Study, was initiated in 1975 to identify factors limiting the performance of municipal STPs. The East study, conducted by Gannett Fleming Corddry and Carpenter (GFCC) Inc. on behalf of EPA (2), screened 120 STPs in EPA Region III and selected 30 facilities for comprehensive review. The West study, conducted by M and I Inc. Consulting Engineers, focused on facilities in EPA Regions VII and VIII, prescreening 163 facilities, shortlisting 63 for more detailed analysis and selecting 30 for comprehensive review (3). This was subsequently expanded to 50 facilities in a Phase 2 study (4). The major outcome of the East-West study, in addition to identifying the most common factors limiting plant performance in the United States, was the development of the Composite Correction Program (CCP) approach to improving plant performance.

The CCP approach emphasizes optimizing of existing facilities as the initial step in performance improvement, rather than capital works and plant expansion. While it is recognized that, at some facilities, design limitations are a significant contributor to non-compliance, the emphasis on process optimization reflects the findings of the East-West study. For example, in the analysis of the 50 western STPs, it was identified that four of the ten most prevalent factors limiting performance were operational in nature and that the three most commonly identified were all operations-related. Similarly, in the 30 eastern STPs, five of the ten most prevalent factors limiting performance were operational. More details regarding the findings of these investigations are included in Section 3.4 of this report. As a result of these findings, a major provision of the U.S. EPA's National Municipal Policy issued in 1984 was that non-complying facilities must develop a Composite Correction Plan identifying causes of non-compliance and outlining corrective measures to be taken to rectify the problems (5). A step-by-step STP evaluation procedure has been developed by EPA to identify facilities where optimization appears to be a practical solution to performance problems (6). This approach has been successfully demonstrated at a number of U.S. facilities (7).

In May of 1991, the Ontario Ministry of the Environment in cooperation with Environment Canada and the Municipal Engineers Association (MEA) initiated an investigation similar in nature but smaller in scope than the East-West study. The overall project was comprised of two parallel project stages, termed Study 1 and Study 2. Study 1 was further sub-divided into two components, Phase 1 and Phase 2.

The overall objective of Study 1 - Phase 1 was to identify the principal factors limiting performance at Ontario STPs and to recommend optimization approaches to address these performance limiting factors. The overall objective of Study 1 - Phase 2 was to demonstrate the effectiveness of the optimization approaches recommended in Phase 1 at selected STPs which were included in the Phase 1 portion of the study. Study 2 was designed to evaluate the U.S. EPA's Composite Correction Program as a tool for diagnosing and subsequently improving the performance of Ontario STPs.

It is the common goal of all activities related to both Studies 1 and 2 to demonstrate that optimization of existing facilities can lead to improved plant performance in a significant number of cases. Optimization may reduce the need for expensive capital expansion of treatment works. As the U.S. experience has shown, the historic approach, in which poor performance is rewarded by the allocation of capital grants for expansion, has not been successful in eliminating non-compliance because, in many cases, the performance limiting factors are not design or capacity related (3). A systematic review to identify all causes of non-compliance and the application of a comprehensive plan to address all of the factors limiting performance is needed.

This report presents the findings of Study 1 - Phase 1. The outcome of the parallel Study 2 are presented in a separate report (8).

1.2 OBJECTIVES

The specific objectives of Phase 1 of Study 1 were as follows:

1. To review the design, operation and historic performance of twelve selected STPs in Ontario which have had a history of performance problems as demonstrated by poor effluent quality in terms of BOD_5 and/or TSS concentrations.

2. To review major process studies conducted at selected Ontario STPs and aimed at identifying performance limitations and means of optimizing process performance.

3. Based on the STP assessments conducted during this study and the review of other process studies, to identify the major performance limiting factors which result in elevated concentrations of BOD_5 and TSS in plant effluents.

4. To develop recommendations which involve operational changes and process optimization which would address the major performance limiting factors identified at Ontario STPs during this investigation.

5. To estimate the possible effects of regulations being considered under the MISA program to reduce raw sewage bypassing and to achieve partial nitrification on the performance status of the selected STPs.

6. To develop order-of-magnitude cost estimates associated with upgrading STPs province-wide to achieve consistent compliance with effluent BOD_5 and TSS limits through process optimization.

1.3 REPORT FORMAT

The body of this report compiles the findings of the investigations at the individual STPs visited during Phase 1 and the results of the process studies undertaken at other Ontario STPs. Detailed site reports and process analyses of the 12 STPs reviewed in Phase 1 are included in a separate Appendix A to the report.

In Section 2.0 of the report, the scope of the Phase 1 investigation is reviewed and the study methodology is summarized.

Section 3.0 presents the factors which were identified most commonly as limiting facility performance in the 12 STPs reviewed and in the STPs which had been the subject of process studies. The findings of this investigation are compared to the findings of other studies which have had a similar goal of defining the causes of performance problems at municipal STPs. Issues related to bypassing and nitrification under the MISA programme are also discussed in Section 3.

In Section 4.0, approaches to address the factors identified as limiting performance in Ontario STPs are presented. The cost implications of STP process optimization are also discussed in Section 4.

2.0 PROJECT SCOPE AND METHODOLOGY

2.1 OVERVIEW OF SCOPE OF STUDY 1 - PHASE 1

The goal of Phase 1 of Study 1 was to determine the principal performance limiting factors at municipal STPs in Ontario and to assess the possibility of improving plant performance in the short-term by operational changes and process optimization. In Phase 1, 12 STPs with a history of performance problems were evaluated to identify the factors limiting performance and to develop recommended approaches to improve performance. This study focused specifically on plants at which the performance problems related to BOD_5 and TSS removal. An earlier study (9,10,11,12) had reviewed the causes of and solutions to non-compliance with effluent total phosphorus (TP) limits. It should be noted however that many of the factors identified as limiting performance in terms of BOD_5 and TSS removal will also limit plant performance in terms of TP removal.

The analysis of the 12 STPs included in Phase 1 was based on historic data, available design data and information collected from plant operating and administrative staff during site visits to the facilities. No monitoring, sample collection or analysis was undertaken during this phase of the investigation.

In addition to the 12 STPs visited and evaluated in Phase 1, a further seven STPs which had been the subjects of intensive process study in the past five years were included in the analysis. Site visits were not made to these sites. Rather, the process reports produced from the earlier investigations were solicited from the operating authorities and reviewed. The key findings of these process studies were then used to augment the information obtained from the other 12 STPs.

2.2 SELECTION OF FACILITIES FOR ASSESSMENT

Plants included in Phase 1 of Study 1 were selected by the Project Technical Steering Committee based on a screening of Ontario STPs. Only mechanical secondary treatment facilities incorporating a biological process in common use in Ontario (e.g. conventional activated sludge, extended aeration including oxidation ditch, high rate activated sludge and contact stabilization) were to be considered for inclusion in Phase 1. Mechanical secondary STPs in Ontario were ranked according to the number of times that the effluent quality on a monthly average basis exceeded pre-defined performance objectives. These performance objectives were established by applying the procedures outlined in the MISA Issues Resolution Process final report (13) to monthly average effluent quality data from the various categories of secondary treatment technologies being used in Ontario. The analysis utilized data contained in the MOE UMIS (Utility Monitoring Information System) database for the period from 1986 to 1988. For extended aeration plants, the data analysis produced performance objectives of 15 mg/L BOD_5 and 20 mg/L TSS. For activated sludge plants including high-rate and contact stabilization facilities, effluent objectives of 25 mg/L BOD_5 and 25 mg/L TSS were generated. Performance data contained in the UMIS database for the period 1986 to 1990 were used to identify plants which did not consistently meet these performance objectives. It should be noted that the performance objectives applied do not necessarily represent compliance limits. Therefore, plants not meeting these objectives are not necessarily in non-compliance with their discharge limits.

From this ranking, 28 candidate plants with performance problems were identified for possible inclusion in the study. Of these 28 facilities, eight had been or were proposed to be the subject of intensive process studies which were to be reviewed as part of the Phase 1 program (refer to Section 2.3). A further four STPs utilized secondary processes which were not considered to be in "common use" in Ontario, had been decommissioned or had undergone a recent major expansion. Hence, these 12 STPs were deleted from the short-list.

The remaining 16 STPs were contacted by telephone by a member of the Technical Steering Committee in order to define the current plant status and to confirm their interest in participating in the proposed investigation. These phone contacts eliminated a further four facilities which were in advanced stages of expansion or upgrading. The elimination of these four STPs from the short-list produced the 12 STPs identified in Table 1 for inclusion in the Phase 1 program. There are a number of key features associated with the 12 STPs included in Phase 1.

1. The selected facilities represented both Northern and Southern Ontario and were well distributed from East to West in the Province.
2. Of the 12 facilities selected, seven (58%) were operated by the Ministry of the Environment and five (42%) were operated by the municipality. This distribution reflected the province-wide situation in which 58 percent of all facilities are operated by MOE and 42 percent are operated by the municipality.
3. The selected facilities covered a reasonable size range, including plants with design capacities as low as 500 m^3/d and as high as 24,970 m^3/d.
4. All biological secondary treatment processes commonly used in Ontario were represented including extended aeration facilities (6), conventional activated sludge plants (4), oxidation ditches (1), and high-rate activated sludge plants (1). Three of the six extended aeration facilities were designed to operate in either the extended aeration or contact stabilization mode.
5. Five of the 12 facilities were "package plants".
6. The facilities appeared to represent a variety of performance problems based on available performance data from 1986 through 1990 which is summarized in Table 2. Some of these facilities (e.g. Plant J) had difficulty achieving performance objectives for BOD_5 but produced excellent effluent quality in terms of TSS. Other facilities (e.g. Plant A and Plant D) had difficulty achieving TSS objectives but produced an excellent effluent quality in terms of BOD_5. Other facilities (e.g. Plant G and Plant K) had difficulties achieving both BOD_5 and TSS performance objectives.

TABLE 1

STPs SELECTED FOR DETAILED ANALYSIS IN STUDY 1 - PHASE 1

Facility	Design Flow (1000 m^3/d)	Plant Type [1]	Location [2]
1. Plant A	24.97	CAS	SW
2. Plant B*	0.68	EA	SW
3. Plant C*	5.45	HR	SE
4. Plant D*	0.95	OD	WC
5. Plant E*	4.54	EA	SW
6. Plant F	1.36	CAS	SE
7. Plant G	3.41	EA	NE
8. Plant H*	0.95	EA	SE
9. Plant I*	0.50	EA	SE
10. Plant J	18.18	CAS	WC
11. Plant K*	0.54	EA	SE
12. Plant L	16.04	CAS	C

(1) EA = Extended Aeration; CS = Contact Stabilization; HR = High Rate; CAS = Conventional Activated Sludge; OD = Oxidation Ditch

(2) Location identified as MOE Region (ie. SE - Southeast Region)

* Indicates facilities operated by the Ministry of the Environment.

TABLE 2

PERFORMANCE HISTORY OF STPs SELECTED FOR DETAILED ANALYSIS (1986 - 1990)

Facility	TSS Performance		BOD_5 Performance	
	No. of Months Exceeding Objective*	Ranking Among 28 Candidate Plants	No. of Months Exceeding Objective*	Ranking Among 28 Candidate Plants
Plant A	19	12	0	28
Plant B	10	24	13	18
Plant C	38	2	24	9
Plant D	16	15	3	26
Plant E	19	11	6	21
Plant F	7	26	6	20
Plant G	29	6	26	7
Plant H	14	18	16	14
Plant I	21	10	15	16
Plant J	1	28	22	10
Plant K	24	9	30	4
Plant L	8	25	12	19

* Performance objectives for extended aeration plants were 15 mg/L BOD_5 and 20 mg/L TSS. Performance objectives for activated sludge plants (conventional and high rate) were 25 mg/L BOD_5 and 25 mg/L TSS.

No specific attempt was made to exclude facilities which were operating at hydraulic or organic loadings in excess of their rated capacity. This approach had been taken in the East-West study (2,3,4) in order to specifically select facilities which were "operable" and where O&M practices could be evaluated. Since a prime objective of this study was to assess factors limiting the performance of Ontario STPs, it was necessary to assess the relative importance of hydraulic and organic overloading to performance problems.

Five of the selected STPs were in the process of or were planning significant construction works, including Plants A, C, F, G and K. These facilities were included in the Phase 1 assessment despite the capital works. Inclusion of these facilities in this study allowed the factors which would not be addressed by the upgrading and expansion plans but which limited plant performance to be evaluated. Such plants would have been excluded from the East-West study in the U.S (2,3,4).

Phase 1 of the West study (3) specifically excluded plants with were known to have extraneous flow problems due to infiltration and inflow (I/I). This exclusion was not made when the 30 eastern plants were selected (2) nor when the 20 additional facilities were evaluated in Phase 2 of the West study (4). When I/I problems were not excluded, I/I was identified to be the second most frequently encountered problem (2,4). No exclusion of plants with I/I problems was made in this study of Ontario STPs.

2.3 STP PROCESS STUDIES INCLUDED IN STUDY 1 - PHASE 1

In order to expand the number of facilities included as a basis for determining the factors limiting performance at Ontario STPs, the findings of process studies undertaken at an additional seven Ontario STPs were included in this phase of the investigation. The plants for which process study reports were available are identified in Table 3, along with a description of each facility, the date on which the process studies were undertaken and the report reference. Also included in Table 3 is a summary of the performance history of these facilities for the period 1986 through 1990. In each case, the study reports were requested from the STP operating authority by the Technical Steering Committee for review. No additional data analysis or information on these facilities beyond that included in the study reports was solicited.

The seven STPs which had been the subject of process studies were all either conventional activated sludge plants (four STPs) or high-rate activated sludge plants (three STPs). Included among these seven plants were some of the larger Ontario STPs including the Duffin Creek WPCP and the Highland Creek WPCP and several plants that were significantly larger than any of the twelve STPs selected for detailed study. Several had a history of performance problems and the identification of causes of these performance problems was typically one of the objectives of the process studies. In most cases, recommendations were provided in the process study reports with respect to methods of improving plant performance.

TABLE 3

STPs FOR WHICH PROCESS STUDY REPORTS WERE REVIEWED

Facility	Design Flow (1000 m^3/d)	Plant Type [1]	Performance History (1986 - 1989) No. of Months Exceeding Objectives***		Date of Process Studies	Report Reference
			BOD$_5$	TSS		
Crystal Beach	3.88	HR	34	22	1986 - 1988	14.
Belleville	54.48	CAS*	20	2	1987 - 1988	15.
Hespeler	9.30	HR	17	30	1986	16.
Highland Creek	218.00	CAS	4	11	1989	17.
Corbett Creek	36.40	CAS/HR**	15	10	1989 - 1990	18.
Duffin Creek	181.80	CAS	19	3	1989 - 1990	19.
Burlington Skyway	93.00	CAS	0	0	1990 - 1991	20.

[1] EA = Extended Aeration; HR = High Rate; CAS = Conventional Activated Sludge.

* 54,480 m^3/d capacity in activated sludge plant and 108,960 m^3/d capacity in physical-chemical treatment plant.

** 18,200 m^3/d as CAS and 18,200 m^3/d as HR.

*** Performance objectives for extended aeration plants were 15 mg/L BOD$_5$ and 20 mg/L TSS.
Performance objectives for activated sludge plants (conventional and high rate) were 25 mg/L BOD$_5$ and 25 mg/L TSS.

2.4 ASSESSMENT PROCEDURES

2.4.1 Site Visits

A one-day site visit to each of the 12 facilities included in the Phase 1 program was conducted. In advance of the visit, a list of information requirements, reproduced in Table 4, was submitted to the operating authority so that these data, if available, would be retrieved in advance of the site visit.

At the site visit, the scope and objectives of all phases of the investigation were explained to the representatives of the operating authority. A review of the information which had been requested of the operating authority was conducted to confirm what was available and what would have to be acquired from other sources (municipality, design consultant, MOE District or Regional offices, or others). The content and format of operating records, budgetary information and other information was confirmed with the operating staff.

A site tour was conducted, under the guidance of the plant superintendent or chief operator, to establish the configuration of the liquid and sludge treatment trains and to confirm the design details. At the same time, the operating strategy for the plant was discussed, plant staffing, sampling and monitoring procedures were reviewed and the maintenance (preventative and emergency) philosophy was identified. The site visit also provided an opportunity to visually assess the condition of mechanical equipment, and the extent and condition of instrumentation at the facility. The perceptions of the operating staff regarding performance limiting factors at the plant which had contributed to the documented poor performance of the facility were solicited. In addition, any operational or design modifications which had been implemented by plant staff in an attempt to address the performance problems were discussed. The availability of personnel, facilities and equipment to undertake fundamental process control monitoring tests, such as sludge settleability, dissolved oxygen concentration, suspended solids concentrations, etc., was noted during the site visits. The type of routine monitoring log sheets used at the plant was also noted and copies obtained for review.

At the completion of the site visit, a site report was completed following a standardized format to compile information provided by the operating authority or evident as a result of the plant tour. These site notes were used extensively in the subsequent analysis of the plant status and the identification of factors limiting performance at each plant.

2.4.2 Data Analysis

The information retrieved from the operating authority during the site visit was returned to the office for detailed analysis. Any performance and operating data which was provided in paper form was entered into an electronic spreadsheet format to simplify analysis. The analysis focused on operating data and performance data for the five year period from 1986 to 1990.

TABLE 4

INFORMATION REQUESTED FROM STPs FOR DETAILED ANALYSIS

1. Operating records for period 1986 to 1990 (total flow, bypassed flow, chemical dosages, sludge generation, MLSS, sludge settleability, etc).
2. Performance data – analytical results for raw sewage, final effluent and other streams (primary effluent, etc.) that are relevant to plant – for 1986 to 1990.
3. Schematic flowsheet and process design data (tank size, design capabilities, etc).
4. Flow data and sampling data (BOD, TSS, phosphorus) for any industries discharging to the STP.
5. Information on STP expansion or upgrading plans.
6. Population and industrial growth projections for the serviced area.
7. Operating and maintenance cost information.
8. Sewer Use Bylaw.
9. Collection system information (bypasses, CSOs, etc).
10. O & M Manual, if available.
11. Sludge haulage records.

The detailed analysis of each facility included the following activities:

- A compilation and summary of the design of the collection system serving the STP, the major liquid treatment unit processes (primary clarification, aeration, secondary clarification) and the sludge treatment unit processes.
- A compilation and summary of available information on industrial contributors to the STP.
- A review and summary of the staffing level at the STP.
- An analysis of the performance history of the plant on a monthly average basis for the five year period. As noted in Section 2.2, performance objectives of 15 mg/L BOD_5 and 20 mg/L TSS were applied to extended aeration facilities and 25 mg/L BOD_5 and 25 mg/L TSS were applied to conventional and high-rate activated sludge facilities. Significant trends in the performance data were identified where possible.
- A process analysis of the facility which considered the hydraulic loading data, the raw wastewater quality and the loadings on the major liquid process units such as primary clarifiers, aeration basins and secondary clarifiers. The adequacy of the individual unit processes was assessed by comparison to generally accepted design standards such as MOE Guidelines (21), WPCF Manuals of Practice (22,23), U.S. EPA Design Manuals (24,25,26) and the "Ten State Standards" (27). Emphasis during this design analysis was placed on the recommended design ranges suggested in the MOE Guidelines since these were developed specifically for Ontario conditions.
- An analysis of the adequacy of the sludge wastage, stabilization and haulage practices at the facility. The recorded or estimated sludge wastage information provided by the plant was compared to the theoretical sludge generation rates. Theoretical sludge generation rates were based on typical ranges in Ontario STPs (21) as well as published data in WPCF Manuals of Practice (28,29) and U.S. EPA Design Manuals (30,31).
- A review of expenditures on operation and maintenance (O&M) for the facility with particular emphasis on the relative expenditures for key items such as operations staff labour and sludge disposal.

The results of this STP analysis were compiled into a comprehensive plant report documenting the plant status in these key areas. During the compilation and analysis of these data, there was frequently a need to contact the STP operating staff to confirm operational data or to acquire additional information regarding the condition of the facility. In some cases, a second visit to the STP was conducted to gather additional information on the facility.

A draft report containing the results of the detailed plant analyses was submitted to the STP operating authority for review to ensure that the technical information compiled was accurate. This plant assessment report, along with the findings of the site visit and discussions with the plant operating staff and other representatives of the operating authority, provided the basis for defining the major factors which were limiting performance at each of the STPs reviewed.

2.4.3 Review of Process Studies

The contents of the seven process reports noted in Table 3 were reviewed to identify the major factors limiting performance at each of these facilities. These reports had generally been prepared using a format similar to that which was used to prepare the plant reports for the 12 plants visited during Phase 1. In most cases, a thorough review of the historical performance data for a significant period up to the time of the process studies was completed. An analysis of the hydraulic and organic loading on the major liquid unit processes was normally included along with a comparison to design standards such as MOE Guidelines (21).

With the exception of the studies at the Highland Creek WPCP, all of these process studies involved extensive monitoring of the plant using a combination of continuous process instrumentation and off-line sampling according to the procedures developed by the Wastewater Technology Centre (32) and refined by Canviro Consultants/CH_2M Hill Engineering Limited (33,34). Hence, a significant amount of dynamic process data was available on each of these facilities on which to base an analysis of process conditions.

These process studies did not always include a comprehensive review of sludge wastage practices nor a determination of the adequacy of the sludge wasting schedule. Where adequate information was available, this review was undertaken as part of this phase of the Stage 1 investigations. Detailed review of staffing, operating and maintenance practices and O&M budgets was generally not a part of these process studies. Hence, it was not always possible to include an analysis of the effects of these factors on STP performance.

2.5 FACTORS INCLUDED IN THE ASSESSMENT

2.5.1 General

Factors which contributed to the poor performance (performance limiting factors) of the 12 STPs visited in the Phase 1 program and the seven STPs for which process studies were available were sub-divided into five specific categories as follows:

i) Design of Liquid Treatment Process Units

ii) Design of Sludge Management Process Units

iii) Operational Factors

iv) Maintenance Factors

v) Administrative Factors

In each of these major categories, specific factors which contributed to the performance problems identified as a result of the historic data review were noted. For each specific factor, its relative contribution to the overall performance problems was qualitatively rated as an "A", "B" or "C" factor based on the data analysis and the other information collected during the site visits and in subsequent discussions with the operating authority. This qualitative rating was based on the following definitions:

- An "A" factor was one which had a major effect on the performance of the facility on a continuous basis.
- A "B" factor was one which had a major effect on the performance of the facility occasionally but not on a continuous basis.
- A "C" factor was one which had a minor effect on the performance of the facility on a continuous basis.

In addition to the ratings applied to each factor, the factors were ranked in the order that they appeared to contribute to the performance problems at the plant.

The process study reports did not always provide sufficient detail in some categories (e.g. Administrative, Maintenance, Design of Sludge Management Process Units) to allow a full assessment of the relative contribution of these factors to the performance of the facilities. Hence, in Section 3.0 of the report, the performance limiting factors identified at the 12 STPs visited in Phase 1 are presented separately from the factors noted in the STPs where process studies were done and then the common factors among all 19 STPs are identified.

The factors identified were those that had made a significant contribution to the poor performance of the plant during the period between 1986 and 1990. In some cases, some or all of these factors had been identified by the operating authority and had been rectified. This was often demonstrated by a noticeable improvement in plant performance during the five-year period being assessed. This often provided further evidence of the opportunities for performance improvements without major capital expenditure.

2.5.2 Factors Considered in the Design of Liquid Treatment Process Units

Based on the historic data, a design evaluation of the major process units in the liquid treatment train was conducted to determine whether the performance problems at the facility under assessment were due to loading conditions beyond the capacity of these processes. This assessment emphasized the major unit processes such as primary clarification (where applicable), aeration and secondary clarification. However, problems with preliminary treatment works were noted if they were deemed to be significant contributors to the performance problems at the facility.

Primary clarification processes were assessed in terms of the average day and peak day hydraulic loads. In situations where significant seasonal flow variations were evident, the hydraulic loadings during the peak loading periods (maximum month) were also considered. The performance of the primary clarifiers was compared to the BOD_5 and TSS removal efficiency expected in a "typical" installation (21). The solids content of the raw sludge from the clarifiers was also compared to the expected range.

Factors considered in the evaluation of the aeration sections of the STPs included hydraulic loading, organic loading (volumetric loading and F/M ratio), estimated operating solids retention time (SRT), estimated oxygen transfer capacity and flexibility in operating mode. The loading at each facility was determined based on the annual average flow and wastewater strengths. In facilities where significant seasonal loading variations were evident, peak loadings were also evaluated.

Factors included in the evaluation of the secondary clarifiers were principally hydraulic loading and solids loading rates. Operating conditions at average flow and peak day flow were considered. In addition, the adequacy of the return sludge system was assessed along with any specific design factors which might contribute to the poor performance (e.g. poor flow splitting, inadequate scum removal, etc.).

The design assessment also considered the adequacy of the instrumentation and control equipment installed in the STP for measurement of key process parameters such as wastewater/effluent flow, return sludge flow and waste sludge volumes. Miscellaneous design deficiencies in any of the liquid treatment process units were also noted.

In situations where loading conditions were deemed to be significant contributors to the performance problems at a particular STP, an attempt was made to determine the cause of the high loadings. The contribution of extraneous flow (infiltration/inflow) to the hydraulic loading of a facility was evaluated based on a comparison of wet and dry weather flow data and an assessment of the per capita flows received at the plant. Hydraulic and organic loading contributions from industrial dischargers, as well as possible discharges of toxic contaminants which might impair the performance of the biological processes, were also evaluated.

2.5.3 Factors Considered in the Design of Sludge Management Process Units

The capability of the sludge management process units at the facility to effectively handle the amount of sludge which would be generated by the liquid treatment train was evaluated to determine if sludge handling capacity was a significant factor contributing to the poor performance demonstrated at the STPs under review.

The loading rates on digestion processes and dewatering processes were compared to typical design ranges (21,28,29,30,31) to determine if the loadings were beyond the capacity of the processes. In addition, the adequacy of storage capacity and disposal capacity (haulage, certified land for disposal, etc.) available at the facility to support the ultimate disposal method being used at the STP were evaluated.

2.5.4 Operational Factors Considered

The assessment of operational factors which contributed to poor performance was more subjective in nature than the assessment of design factors. This assessment compared the operational and process control procedures in use at the facility with those considered to represent "Best Operating Practices" (35,36,37).

Factors which were considered included:

- adequacy of process control monitoring for such key operational parameters as MLSS concentration, sludge settleability, dissolved oxygen concentration, influent and effluent quality, etc.
- adequacy of sludge wastage and disposal programs to maintain control of the solids inventory in the plant.
- level of knowledge of key principles of wastewater treatment plant operation displayed by operating staff and the application of that knowledge to maintain effective process control.
- availability of adequate operating manuals and technical support to assist operations staff in process control operations.
- availability of laboratory equipment including dissolved oxygen probe, settling cylinders, suspended solids filtration/drying/weighing apparatus, etc. needed to complete critical process control tests.
- miscellaneous operational factors which have a direct influence on plant performance. This category would include such factors as poor sludge settleability, rising sludge due to denitrification in clarifiers, and elevated BOD_5 in the effluent due to partial nitrification and the exertion of nitrogenous oxygen demand.

2.5.5 Maintenance Factors Considered

Observations of the condition of key mechanical equipment and the level of housekeeping which were made during the site tour along with discussions with the operating authority regarding the preventative and break-down maintenance programs applied were used to assess the relative contribution of maintenance to the poor performance. Factors considered included:

- presence of an adequate preventative maintenance program to minimize down-time of key mechanical equipment.
- demonstrated knowledge of plant staff regarding equipment maintenance requirements and techniques.
- availability or access to necessary maintenance equipment.
- age and condition of major equipment.

2.5.6 Administrative Factors Considered

As part of the site visits, details regarding staffing, training and budgets were collected to assess the effect of administrative factors on plant performance. Factors considered included the following:

- level of staffing provided for operation and maintenance of the facility compared to the levels considered necessary to conduct process control monitoring and routine maintenance (38,39).

- financial considerations including adequacy of O&M budgets and availability of capital funding for plant upgrading and expansion.

- staff qualifications, including level of training.

- policies and support available from plant administrators and managers to operating staff to assist with improving plant operation.

In this context, administrative factors were considered to be any decision or policy (or lack thereof) made by political, managerial or clerical staff outside the plant which had a direct influence on the ability of the plant operating staff to effectively operate the facility.

2.5.7 Summary of Factors Considered

Table 5 presents a summary of the factors which were considered as contributing to the poor performance of the STPs evaluated.

TABLE 5

FACTORS CONSIDERED
AS CONTRIBUTING TO
PERFORMANCE PROBLEMS

Category	Factor
1. Design of Liquid Treatment Units	a. Hydraulic Loading b. Organic Loading c. Oxygen Transfer d. Extraneous Flow (I/I) e. Industrial Input f. Instrumentation and Control g. Lack of Flexibility h. Miscellaneous Design Deficiencies
2. Design of Sludge Treatment Units	a. Treatment Capacity b. Storage Capacity c. Disposal Capacity
3. Operational Factors	a. Process Monitoring b. Sludge Wastage and Disposal c. Knowledge of Wastewater Treatment Principles d. Manuals and Technical Support e. Availability of Monitoring Equipment f. Miscellaneous Operational Factors
4. Maintenance Factors	a. Preventative Maintenance Program b. Knowledge of Maintenance Procedures c. Availability of Maintenance Equipment d. Age of Equipment
5. Administrative Factors	a. Level of Staffing b. Financial Considerations c. Staff Training d. Support from Administrators

3.0 FACTORS CONTRIBUTING TO POOR PERFORMANCE

3.1 GENERAL

Each of the 12 STPs visited during Phase 1 was evaluated according to the procedures outlined in Section 2.0. Based on this analysis, the relative contribution of each of the 25 factors listed in Table 5 to the poor historic performance of the facility was assessed. The results of the individual plant analyses are included in Appendix A of the report. The reader is referred to these detailed plant reports for discussions of specific problems at a particular facility.

It must be realized that many of the factors being evaluated are inter-related. Assigning a ranking to a number of related complex factors in this situation is difficult because it is not always possible to establish cause and effect relationships based solely on historic data. Furthermore, in some cases, some of the causes of poor performance had already been corrected at the time of the site visit. In many cases, additional plant monitoring and sampling would be required to confirm the relative importance of the specific factors identified.

Generally, the factor that was considered to be the prime cause of poor performance was given the highest rating and other factors which were symptoms related to the prime causal factor were given substantially lower, if any, ranking. For example, extraneous flows to a facility may result in hydraulic overloading under wet weather conditions. In this case, the factor most significantly influencing performance would be "extraneous flow" and not "hydraulic loading". "Hydraulic loading" would be considered to be the most significant factor if the flows under dry and wet weather conditions exceeded the capacity of the process units, causing poor plant performance.

Detailed summaries of the findings of the process studies reviewed in this phase of the investigation are not provided in this report. A brief summary of the major conclusions and recommendations is presented and the reader is referred to the specific reports for more detailed information. As noted in Section 2.3, some of these process studies were intended to support the design of plant expansions rather than process optimization. Hence, the emphasis was primarily on the identification of design limitations rather than on operational problems. Further, more detailed information was typically collected from the liquid treatment processes than from the sludge management processes. These differences need to be considered in comparing the findings from the 12 site visits and the seven process study reports.

3.2 FACTORS IDENTIFIED AT VISITED SITES

At each STP, between eight and ten different factors were identified as contributors to the poor historic performance. Generally, there were different combinations of factors identified at each plant in differing orders of importance.

Figure 1 shows the frequency at which each of the 25 factors was identified in the 12 plants visited. Of the 25 factors included as potential contributors, only five factors were never identified at any plant. These five factors were:

- design sludge treatment capacity
- preventative maintenance programs
- knowledge and training of plant staff in equipment maintenance requirements and techniques
- availability or access to necessary maintenance equipment
- staff qualifications and training

Three of these five factors are maintenance-related.

Table 6 presents the ten most frequently identified factors in descending order. Seven factors were identified as contributing to the poor performance at more than half of the twelve plants evaluated. The most frequently identified factor was the lack of process instrumentation and control (I&C) equipment for key process variables. This was the only factor noted as a contributor at all 12 plants visited. However, in all cases, it was felt to have a minor effect on performance on a continuous basis ("C" factor). Similarly, the availability of adequate O&M manuals or technical support was the fifth most commonly identified factor, noted at nine of the 12 plants visited; however, it was not considered to be a major factor on a continuous basis ("A" factor) at any of these nine plants.

To provide an assessment of both the frequency and relative importance of each factor, "A" factors were given a rating of 3 points, "B" factors were given a rating of 2 points and "C" factors were given a rating of 1 point. The frequency rating was then calculated for each factor by summing the rating at each STP. The maximum frequency rating which could be achieved by any factor would be 36 if the factor was identified as an "A" factor at all twelve plants.

When this assessment procedure was used, the point distribution presented in Figure 2 resulted. Nine factors had frequency ratings higher than ten. Of these, four were liquid process design related and four were operational. The ten highest ranking factors were those identified in Table 7. The same ten factors as noted in Table 6 show up in Table 7; however, the order of importance has changed slightly. The factor most frequently identified with the greatest importance is the adequacy of the sludge wastage and disposal program at the plant (27 points out of a possible 36). The second highest ranked factor based on frequency and importance was the level of knowledge of plant staff regarding the fundamental principles of wastewater treatment and their ability to apply these principles to the operation of their plant (23 points).

FIGURE 1

FREQUENCY OF OCCURENCE OF PERFORMANCE LIMITING FACTORS

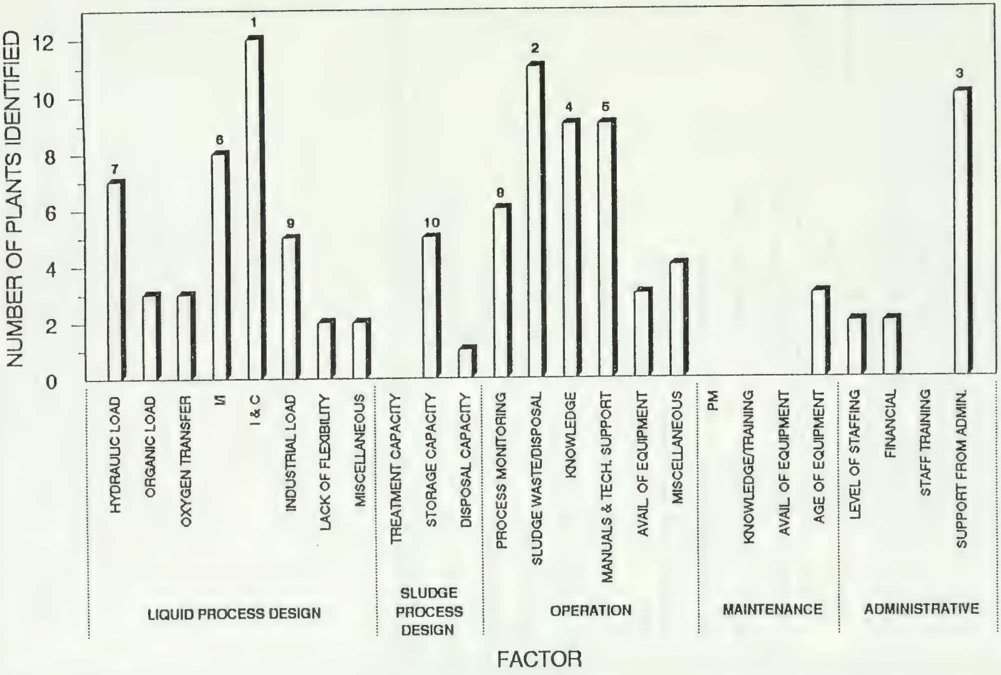


TABLE 6

TEN MOST FREQUENTLY IDENTIFIED FACTORS CONTRIBUTING TO POOR PERFORMANCE

Factor	Category	Number of STPs Where Factor Was Identified
Instrumentation and Control	Liquid Process Design	12
Sludge Wastage and Disposal	Sludge Process Design	11
Support from Administrators	Administrative	10
Knowledge of Wastewater Treatment Principles	Operational	9
Manuals and Technical Support	Operational	9
Extraneous Flow (I/I)	Liquid Process Design	8
Hydraulic Loading	Liquid Process Design	7
Process Monitoring	Operational	6
Industrial Input	Liquid Process Design	5
Sludge Storage Capacity	Sludge Process Design	5

FIGURE 2

FREQUENCY RATING OF PERFORMANCE LIMITING FACTORS

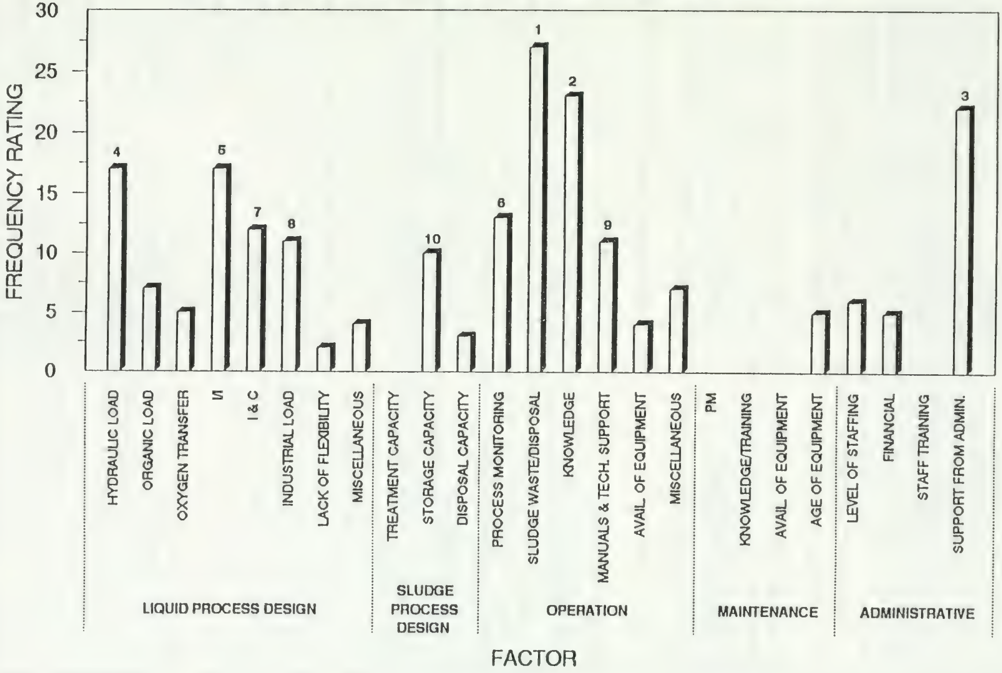


TABLE 7

TEN HIGHEST RANKED FACTORS ACCORDING TO FREQUENCY RATING

Factor	Category	Frequency Rating*
Sludge Wastage and Disposal	Sludge Process Design	27
Knowledge of Wastewater Treatment Principles	Operational	23
Support from Administrators	Administrative	22
Hydraulic Loading	Liquid Process Design	17
Extraneous Flow (I/I)	Liquid Process Design	17
Process Monitoring	Operational	13
Instrumentation and Control	Liquid Process Design	12
Industrial Input	Liquid Process Design	11
Manuals and Technical Support	Operational	11
Sludge Storage Capacity	Sludge Process Design	10

* Based on 3 points for A, 2 points for B and three points for C rating. Refer to Section 2.5.1 for definition.

The 25 factors were also ranked in the order of their importance to the poor performance at each of the 12 plants. In this evaluation, the most important factor at a particular plant was given a score of 10, the second most important was given a score of 9, etc. The total scores for each factor for all 12 plants were then summed. The results of this analysis are presented in Figure 3. In this case, the maximum point score achievable is 120 if the same factor was the most important contributor at all 12 plants (12 plants x 10 points/plant = 120). The ten most important factors based on this ranking system are listed in Table 8. The three most important factors based on this ranking are the same as identified in Table 7 based on a frequency rating.

The same factors make up the ten most important by all three ranking systems (Tables 6, 7 and 8). However, the order of importance changes somewhat from table to table as illustrated in the summary provided in Table 9. Of these ten factors, four are related to the design of the liquid treatment unit processes, one is related to the design of the sludge treatment unit processes, four are operational and one is administrative in nature.

3.2.1 Liquid Treatment Unit Design Factors

As noted, available instrumentation and control (I&C) equipment for key process variables was considered to be inadequate at all 12 STPs. In general, the deficiencies were related to the capability to measure return sludge rates and waste sludge rates, key operational variables in a secondary treatment process. Only two of the 12 plants (Plant A and Plant L) had the capability to measure both RAS and WAS rates continuously and used these data for process control. Plant J measured RAS rates and had equipment to monitor WAS flows, but the WAS meters had not been functional for some time. Five of the plants (Plants B, C, H, I and K) used air lift systems for sludge return and wastage and had no mechanism to measure either flowrate. In these plants, the operating staff had no capability to adjust return sludge rates in response to changing flow conditions or sludge settleability. At Plant E, there was no capability to adjust RAS flowrate due to the design of the integral clarifier. Other I&C problems related to inaccurate raw sewage or final effluent flow meters and lack of dissolved oxygen monitoring equipment in facilities subject to significant organic loading and/or oxygen demand variations. In all 12 plants, the lack of adequate I&C equipment was considered to be a "C" factor in terms of its effect on plant performance. However, it was the most frequently encountered problem and ranked seventh in terms of both measures of relative importance.

Extraneous flow (I/I) to the treatment facility was the sixth most frequently encountered factor, noted as a contributor at eight of the 12 plants visited. It was the fourth or fifth most important factor in terms of effect on performance. Figure 4 illustrates the average peaking factors recorded at the 12 STPs for the five year period studied. With the exception of Plant C and Plant K, the peaking factors all exceed 2.0. Peaking factors at six of the 12 plants exceed 3.0. In six of the plants (Plants A, C, F, G, H and J), the recorded peaking factor underestimates the extent of the extraneous flow problem since a significant flow under peak conditions does not enter the plant (refer to Section 3.5). Average day per capita flows at the 12 facilities are shown in Figure 5. The high per capita flow recorded at Plant L is due primarily to industrial contributions rather than extraneous flow. Similarly, high per capita flows at Plant E are at least partially due to

FIGURE 3

IMPORTANCE RATING OF FACTORS LIMITING PERFORMANCE

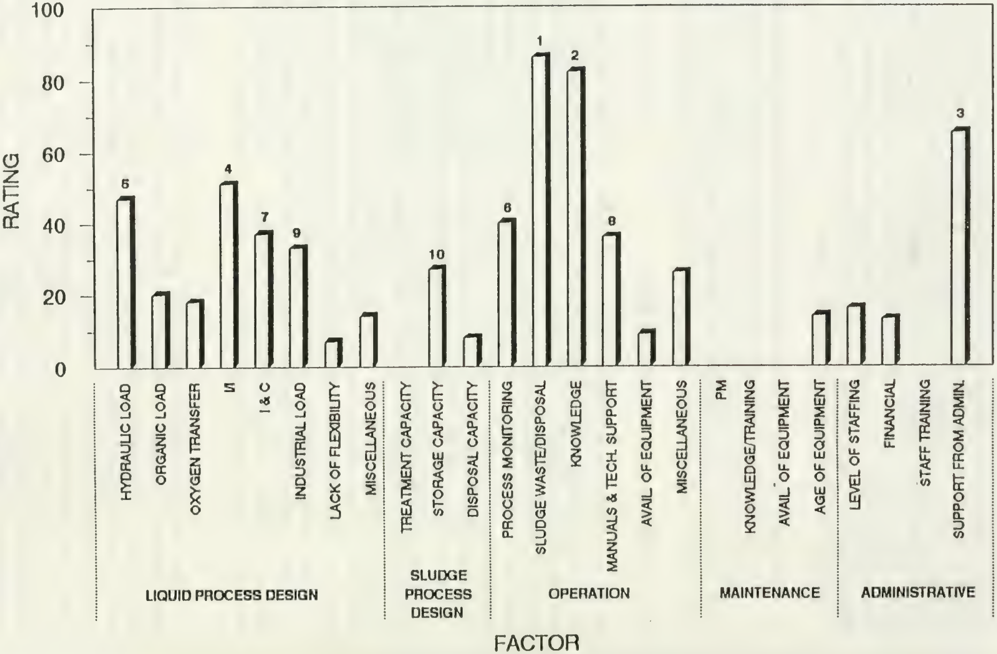


TABLE 8

TEN HIGHEST RANKED FACTORS
BASED ON IMPORTANCE RATING

Factor	Category	Rating*
Sludge Wastage and Disposal	Sludge Process Design	86
Knowledge of Wastewater Treatment Principles	Operational	82
Support from Administrators	Administrative	65
Extraneous Flow (I/I)	Liquid Process Design	51
Hydraulic Loading	Liquid Process Design	47
Process Monitoring	Operational	40
Instrumentation and Control	Liquid Process Design	37
Manuals and Technical Support	Operational	36
Industrial Input	Liquid Process Design	33
Sludge Storage Capacity	Sludge Process Design	27

* Based on highest ranked contributor receiving 10 points, second highest ranked contributor receiving 9 points, etc.

TABLE 9

SUMMARY OF RANKING OF TEN MOST PREVALENT FACTORS

	Rank			
Factor	Frequency	Frequency Rating	Importance Rating	Nature of Problem
Instrumentation and Control	1	7	7	Liquid Process Design
Sludge Wastage and Disposal	2	1	1	Operational
Support from Administrators	3	3	3	Administrative
Knowledge of Wastewater Treatment Principles	4	2	2	Operational
Manuals and Technical Support	5	9	8	Operational
Extraneous Flow (I/I)	6	5	4	Liquid Process Design
Hydraulic Loading	7	4	5	Liquid Process Design
Process Monitoring	8	6	6	Operational
Industrial Input	9	8	9	Liquid Process Design
Sludge Storage Capacity	10	10	10	Sludge Process Design

FIGURE 4

AVERAGE PEAKING FACTOR

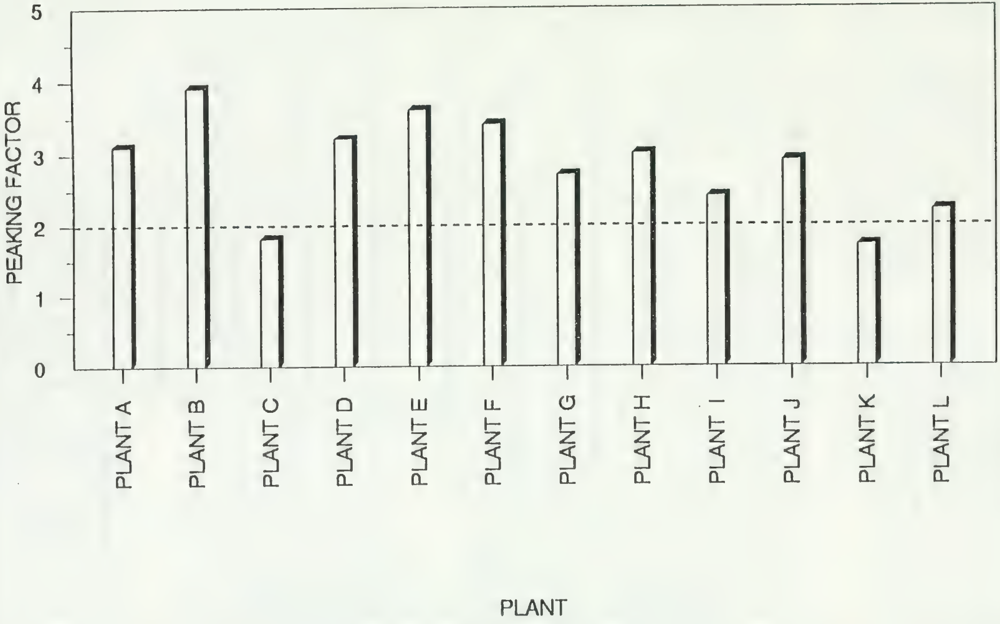
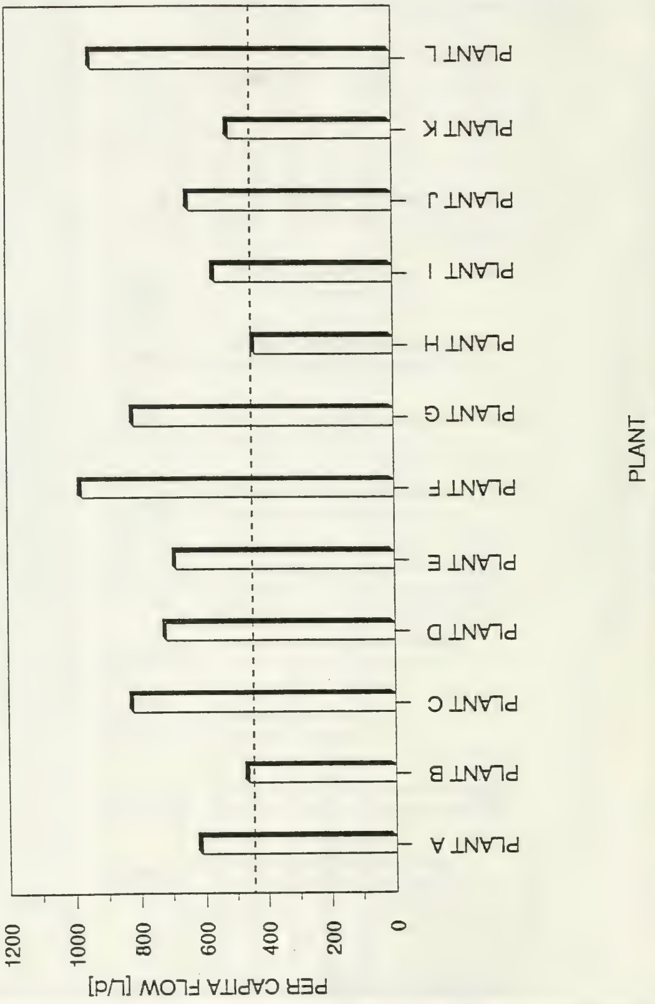


FIGURE 5

AVERAGE PER CAPITA WASTEWATER FLOW



industrial input. Six other plants (Plants A, C, D, F, G and J) have average day per capita flows in excess of 600 L/d. As noted, per capita flows at several of these facilities are higher than reported due to bypassing upstream of the plant flow monitoring equipment. Although I/I was commonly reported as a factor, it was only twice noted as having a major effect on a continuous basis ("A" factor). It was not identified as the most important factor in either case. Generally, I/I creates short-term performance problems which are not encountered on a continuous basis. However, I/I can result in non-compliance with short-term (monthly) average based effluent limits.

Excessive hydraulic loading was noted at seven facilities. It was the fourth or fifth rated factor in terms of relative importance depending on the rating system applied. The secondary clarifier was the unit process most affected by high hydraulic loading. In some cases, the high loading was related to extraneous flows in the collection system which occurred on a continuous basis due to groundwater infiltration into a deteriorating sewer system. Figure 6 compares the average day flow for the five year period for each plant to the design capacity. Based on the long-term average flow, three of the 12 plants (Plants A, G and K) received flows in excess of their design capacity. An additional five plants (Plants B, C, D, F and I) had five year average flows in excess of 90 percent of the rated capacity and exceeded the rated capacity in some years. Five of these eight plants (Plants A, C, D, F and G) were in the process of expanding and/or upgrading. Average day flows in excess of the design rating does not necessarily mean that hydraulic loading is a significant problem. For example, Plant F operated, on average, at 93 percent of its hydraulic capacity, but hydraulic loading was not identified as a factor at this facility due to the conservative design of the liquid treatment units. At this facility, the peak day surface overflow rate of the primary and secondary clarifiers has been less than 35 $m^3/m^2.d$ in most years which is low by most design standards.

At several of the smaller facilities including Plants B, C, D, I and K, the hydraulic loading problem is compounded by the operation of on/off lift pumps serving the facility. As illustrated in Figure 7, one of the raw sewage pumps at Plant K delivers five times the average daily flow capacity of the plant. At other plants, the output of the service pump is 3 to 4 times the average flow capacity of the plant. At peak flow conditions with two pumps operating, the instantaneous peak flow may be 5 to 10 times the design capacity. In these circumstances, the daily flow data do not present a representative indication of the severity of the hydraulic loading applied to the clarifiers at the facilities. Hydraulic loading may be a serious problem on a continuous basis because of the design of the sewage lift station despite the fact that the average flow is well below design and wet weather flows are not severe.

Industrial wastewater was noted as a factor at five plants, making it the ninth most frequently encountered problem. It had a similar ranking in terms of relative importance as a contributor to poor plant performance. It was the most important factor at one facility (Plant L). Generally, organic (BOD_5) loading from the industries tributary to the treatment facility was the cause of the problem rather than discharge of toxic contaminants which inhibited plant operation. The variability of the BOD_5 loading was as much a factor as the magnitude of the loading. However, high metal concentrations in sludge which affected the disposal program was noted at one plant (Plant E) due to industrial discharges. Industrial loading was evaluated as a factor affecting performance

FIGURE 6

AVERAGE FIVE YEAR FLOW AS PERCENT OF DESIGN FLOW

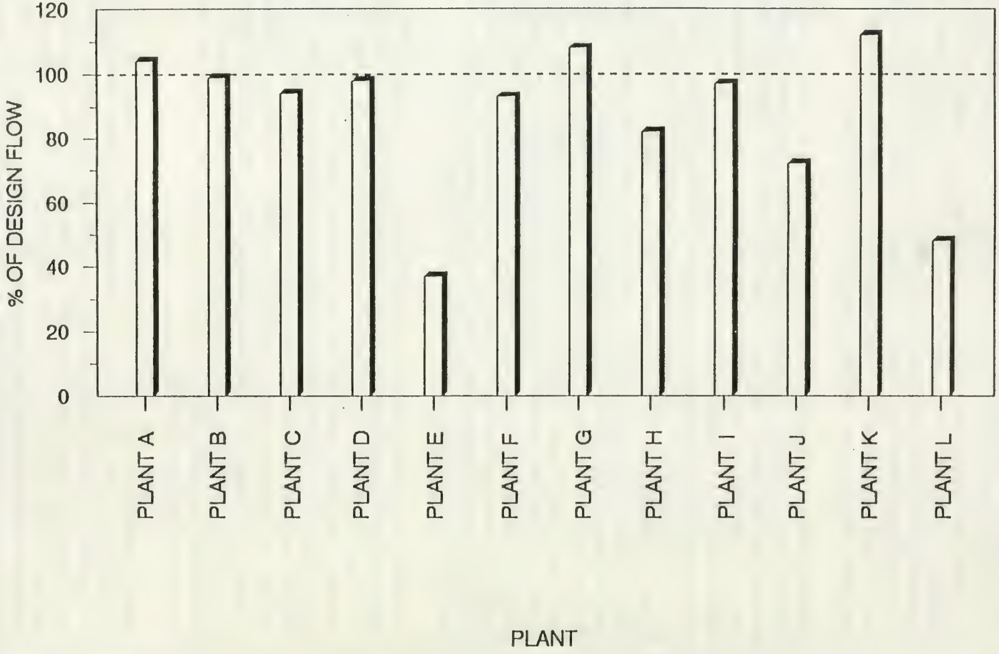
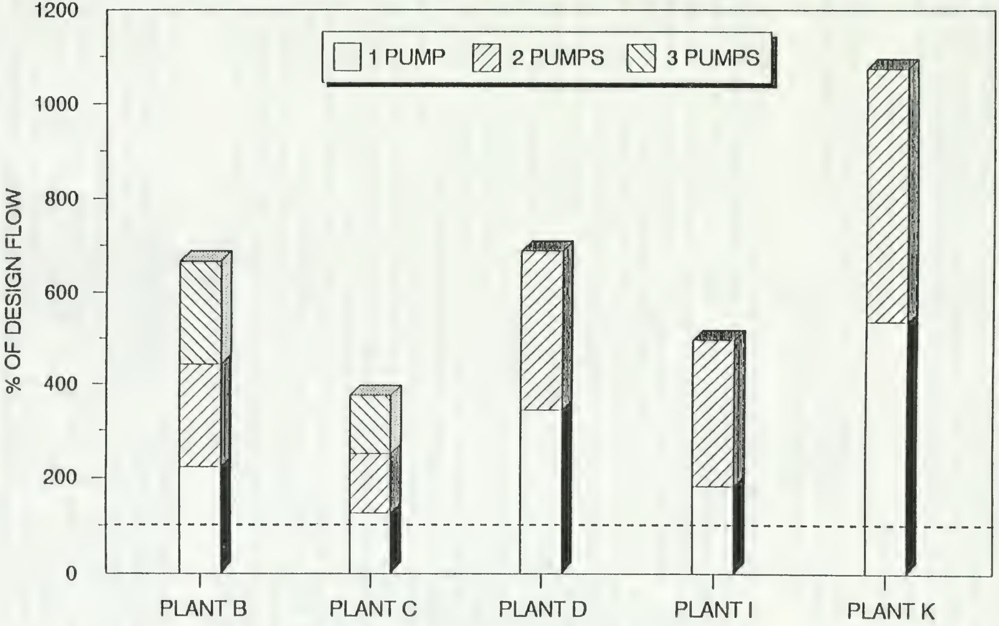


FIGURE 7

COMPARISON OF PUMP STATION OUTPUT TO PLANT DESIGN CAPACITY



only if it contributed to poor effluent quality in terms of BOD_5 or TSS concentrations. This evaluation did not include an assessment of the potential pass-through of other contaminants such as metals or trace organics due to industrial discharges to the sanitary sewer system. At most plants, there was little data available with respect to the volumes of wastewaters discharged to the plant from industrial sources or the characteristics of these discharges.

The other four factors related to the design of the liquid treatment unit processes were all noted at two or three facilities, occasionally as a major factor affecting performance on a continuous basis ("A" factor).

High organic loading on the treatment system was noted at three plants (Plants A, D and L). At all three of these plants, the high loading was the result of industrial discharges. As illustrated in Figure 8, all of the STPs visited with the exception of Plant D and Plant L were operating at organic loadings substantially lower than design. In many cases, this reflects the relatively weak sewage received at these plants due to the extraneous flow into the collection system. Plants which are operating at near hydraulic capacity still have available organic treatment capacity in the biological system. At two of the three plants experiencing excessive organic loading, limited oxygen transfer capacity was also noted as a factor (Plant A and Plant D). At Plant L, adequate oxygen transfer capacity was available to handle the organic loading and to nitrify on a consistent basis. One other facility (Plant K) had occasional oxygen transfer problems caused by plugging diffusers and inadequate aeration basin freeboard. As illustrated in Figure 9, all of the plants with the exception of Plant D had oxygen transfer capacity equal to at least 150 percent of the carbonaceous oxygen demand. Most of the plants had sufficient oxygen transfer capacity to meet the nitrification requirements as well under average loading conditions. At Plant C, there was insufficient raw sewage nitrogen concentration data to establish the oxygen demand associated with nitrification. At Plant I, the oxygen transfer capacity could not be estimated with any degree of confidence since the air flow rate to the submerged turbine was unknown. Hence, data for these two plants is not presented in Figure 9. Since effluent data from Plant I showed a consistent high degree of TKN removal when effluent TSS concentrations were at reasonable levels, it is assumed that oxygen transfer capacity exceeds the demand associated with BOD_5 removal and nitrification under average loading conditions. More detailed discussion regarding the upgrading required at these facilities to achieve nitrification is included in Section 3.5.

Most of the facilities visited had limited flexibility in terms of operating mode. At the plants where some flexibility in operating mode was available (extended aeration, contact stabilization, step feed, etc.), plant staff had not utilized this flexibility. However, at only two plants (Plant E and Plant L) did the lack of flexibility directly affect effluent quality. At Plant E, there was no flexibility to adjust return sludge rates due to the integral clarifier design. At Plant L, the plant operation was limited to complete mix activated sludge only. Flexibility to operate the parallel aeration basins in a series mode would be beneficial in light of the highly variable industrial load received at this plant. At the smaller plants, there was generally only one secondary clarifier (Plants B, D, F, H, I and K). At most of these plants, this clarifier had not been taken out-of-service for inspection or major maintenance since plant commissioning because no back-up was

FIGURE 8

COMPARISON OF AVERAGE ORGANIC LOADING WITH DESIGN ORGANIC LOADING

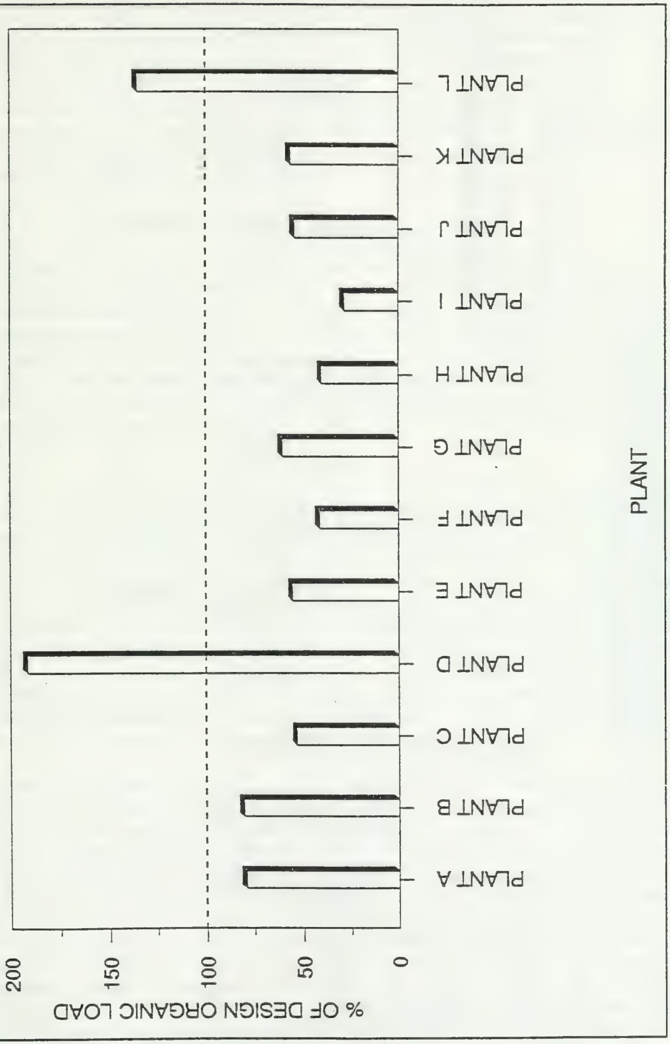
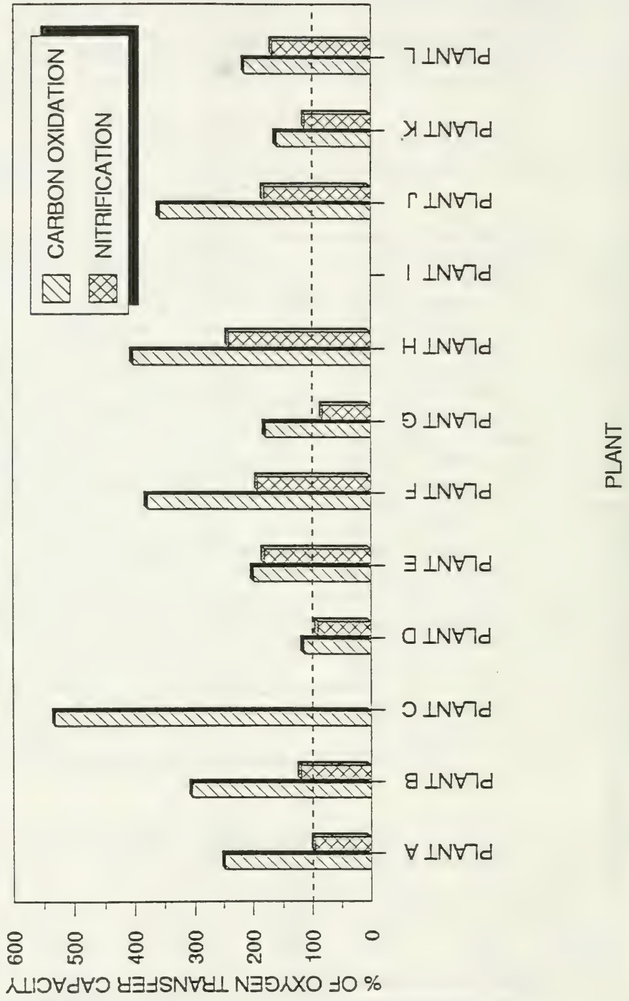


FIGURE 9

COMPARISON OF OXYGEN REQUIREMENTS WITH ESTIMATED TRANSFER CAPACITY



available. Although this had not resulted in major performance problems at these facilities, it was a concern because of the potential implications of operating for an extended period without treatment if the clarifier failed.

Miscellaneous liquid treatment system design factors were noted as problems at two plants. At Plant K, possible preliminary treatment problems were noted. At Plant A, the use of the lagoons for treatment of peak flows and for polishing was found to deteriorate effluent quality significantly.

3.2.2 Sludge Treatment Unit Design Factors

Inadequate sludge treatment capacity was not identified as a factor affecting performance at any of the 12 facilities visited. This evaluation did not assess the suitability of the sludge after treatment for disposal. Only the possible effects of inadequate sludge treatment capacity on the effluent quality from the facility in terms of BOD_5 and TSS concentrations were considered. The majority of the facilities visited (Plants B, C, D, E, G, H and K) treated sludges by "aerobic digestion" prior to disposal. In all cases except Plant C, the retention time provided in the "digester" would probably not result in a significant degree of stabilization of the sludges, particularly under cold weather conditions.

Ten of the 12 STPs applied sludges to agricultural land, as identified in Table 10. Four to six months storage capacity is suggested at such facilities to account for periods when the land is not accessible due to climatic conditions (40). As illustrated in Figure 12, many of the plants disposing of waste sludges to agricultural land had less than one month of sludge storage capacity on site. At five plants, the amount of sludge storage available was identified as a factor directly affecting effluent quality. This was the tenth most frequently identified problem in the 12 plants and the tenth most important in terms of its relative contribution to poor plant performance (Table 9). Some plants had arranged off-site storage or constructed additional on-site storage to augment the amount of storage provided in the original plant design. Without this initiative on the part of plant staff or administrators, inadequate sludge storage would have ranked even higher among these 12 plants as a factor affecting performance.

Capacity for disposal of excess sludge was a factor at only one plant (Plant E). In this case, metal contaminated sludges had to be stockpiled in part of the liquid treatment tankage because no suitable alternate disposal option was available. At one other plant (Plant B), sludge storage and disposal capacity was not a factor during the period from 1986 to 1990, but had become a significant factor in 1991 because of the closure of off-site storage and the lack of approved land for disposal. Although sludge disposal capacity was not highly ranked as a factor affecting performance among these 12 plants, it was noted that there was a general lack of a coordinated land application program. Approval of sites was time-consuming and lengthy. In many cases, an adequate inventory of approved sites was not maintained to ensure that the utilization program could be operated without interruption. Plants in the same vicinity operated totally independent sludge disposal programs when coordination of the individual programs would be beneficial. A coordinated program might also allow the provision of more cost-effective centralized storage facilities. Few plants have contingency plans in place

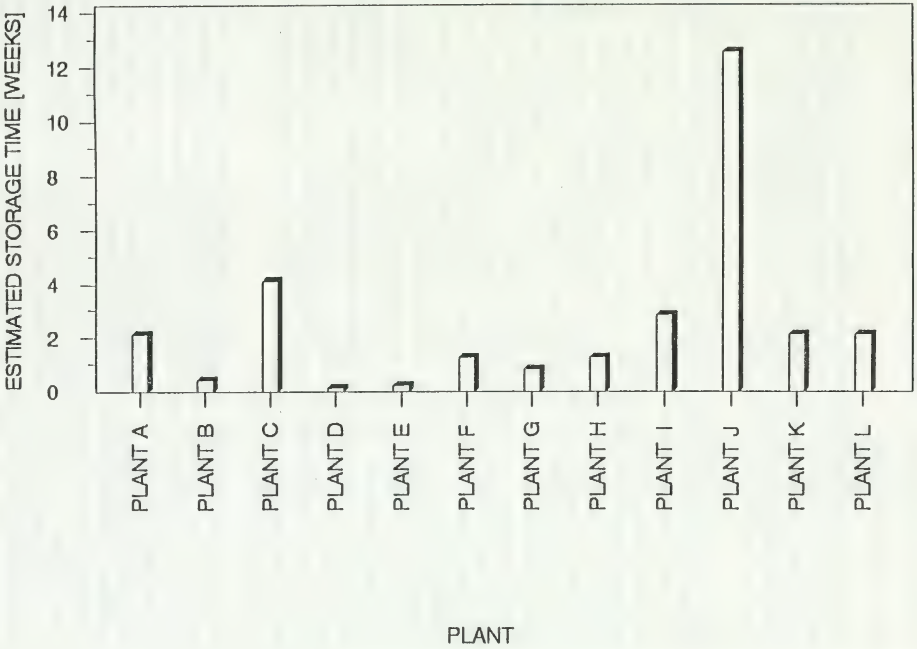
TABLE 10

ULTIMATE SLUDGE DISPOSAL METHOD

Plant	Sludge Disposal Method
Plant A	Dewatered, Air-dried, Top Dressing at Landfill
Plant B	Hauled to Lagoons at Landfill, Land Applied
Plant C	Land Application
Plant D	Land Application
Plant E	Land Application
Plant F	Land Application
Plant G	Land Application
Plant H	Land Application
Plant I	Land Application
Plant J	Land Application
Plant K	Air-dried, Top Dressing at Landfill
Plant L	Land Application

FIGURE 10

ESTIMATED SLUDGE STORAGE TIME



to ensure that sludge disposal could be maintained in the event that sludges could not be disposed to agricultural land because of metal contamination. This is a particular concern for facilities that have industrial dischargers who are sources of heavy metals and have a history of metal contamination in their sludges.

3.2.3 Operational Factors

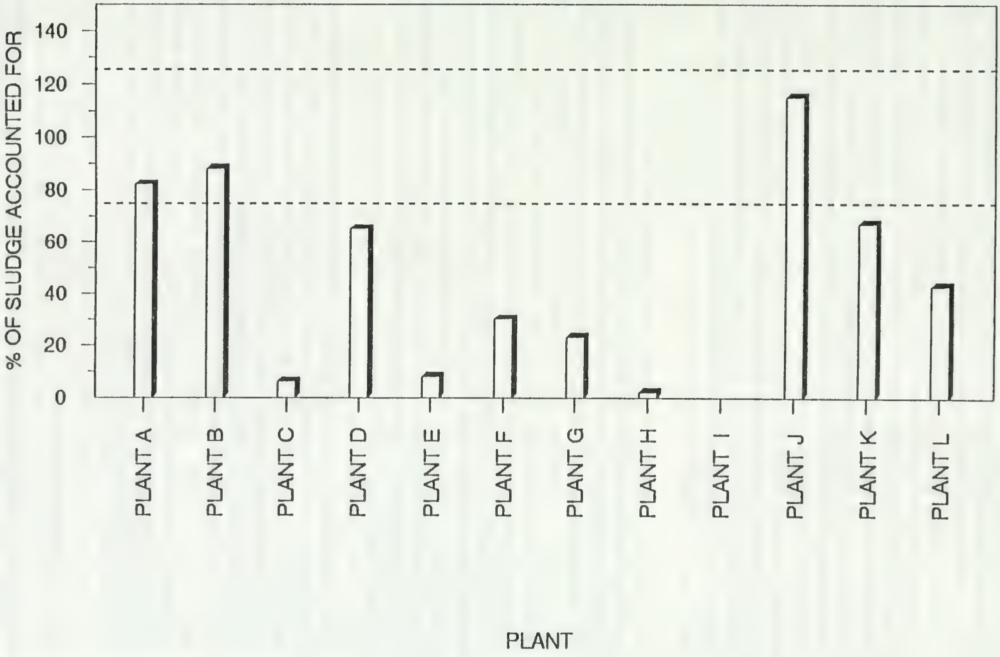
All six of the operational factors were identified as contributing to poor performance at some of the facilities visited. Four of the ten most frequently identified problem areas were operational and the two most significant factors noted were in this category. Many of the operational factors are inter-related. It was not uncommon to find that all six of them were problems at a particular plant.

Inadequate control of sludge wasting and disposal was noted at 11 of the 12 facilities. This was the most important factor affecting plant performance overall although it was not ranked as the most important factor at any individual plant. Only Plant A effectively maintained solids inventory control in the secondary portion of the plant, pumped sufficient excess sludge from the liquid treatment train to the sludge treatment units and removed enough sludge from the plant for final disposal to maintain a solids balance in the system. At some plants, the ability to waste sludge from the system was controlled by the availability of sludge storage or disposal capacity. At other plants, there was a lack of appreciation for the need to maintain solids inventory control in the biological process. At many of the smaller facilities, there was no monitoring done to determine the amount of sludge which should be wasted to maintain the process and no measurement made of the amount of sludge removed from the biological system. As illustrated in Figure 11, only three plants--Plant A, Plant B and Plant J--accounted for between 75 and 125 percent of the theoretical sludge generated in their haulage records. At some of the plants, less than ten percent of the sludge which should have been produced was accounted for in the plant records. This suggests that large quantities of solids must be lost from the system to the plant effluent, directly influencing effluent quality. Poor sludge inventory control was also demonstrated by highly variable MLSS concentrations in the aeration basin of the plant. The aeration basin was often used for sludge storage during periods when sludge could not be disposed of on agricultural land and other storage was not available.

The second most important factor influencing the performance of these 12 facilities was the lack of knowledge regarding the key principles of biological wastewater treatment operation and the ability of the operating staff to apply these principles to the operation of their plant. This problem was noted at nine of the 12 plants and was considered to be the most important factor at five plants. It is noteworthy that "staff training" was not noted as a factor at any of the 12 plants (see Section 3.2.5). In all cases, plant staff had attended and were encouraged to attend training courses and were "qualified" to operate their facilities. Yet, many operators did not display an ability to apply this training to the optimization of the operation of their plants. This lack of understanding was demonstrated by the lack of process monitoring conducted to determine the status of the operation and support process control decisions. In some plants, the only sampling done was that required by the MOE for compliance purposes. The lack of sludge wastage control discussed above reflects the lack of understanding by plant staff regarding the importance of sludge inventory control to proper biological treatment plant operation.

FIGURE 11

COMPARISON OF ACTUAL AND THEORETICAL SLUDGE GENERATION



Lack of adequate process monitoring was identified as a problem at six facilities and was the sixth most important factor identified overall. In many cases, this lack of monitoring was a direct result of the lack of understanding of the importance of collecting appropriate process data to support process control decisions. However, in selected cases, lack of staff and lack of equipment to conduct key testing was a direct contributor to the lack of monitoring conducted at the plant. Lack of equipment to conduct process monitoring was, in fact, noted at three plants as a factor directly influencing plant performance. A disturbing number of plants were operated with no data regarding the concentration of solids in the aeration basin, the dissolved oxygen concentrations, the settleability of the sludge or the amount of sludge wasted from the process. Few plants routinely calculated F/M ratio, SRT or any other loading based parameter for the biological system. Only one plant (Plant A) routinely plotted trends for key performance and operating data. Plants operated by MOE routinely logged the operational data collected into a standard computerized database, but did not generally utilize the capabilities of this database to support process control decisions.

Few of the plants had O&M manuals which provided technical information relevant to the control of the operation of the process. This was noted as a problem at nine facilities, although it was never considered to be a major factor affecting performance on a continuous basis ("A" factor). Manuals that were available generally contained manufacturers' information on mechanical and electrical equipment to support maintenance activities rather than process information. At the smaller plants, other technical support resources, such as WPCF Manuals of Practice or technical reports, were very limited. Senior management generally supplied administrative support rather than technical support to operating staff. Inspection of the facilities by regulatory officials usually focused on deficiencies related to regulations rather than technical assistance to address process control problems. Seldom was technical advice available from consulting engineers or other sources to assist plant operators in addressing process problems at their facilities.

Other miscellaneous operational factors directly affecting plant performance were noted at four plants. In three of these cases (Plant A, Plant H and Plant L), poor sludge settleability was the specific factor noted. At both Plant A and Plant L, high strength industrial discharges probably contributed to the poor settleability of the secondary sludge. At Plant H, inadequate solids inventory control, possibly in conjunction with elevated hydrogen sulphide concentrations in the raw wastewater, are likely causes. In the fourth case (Plant J) where miscellaneous operational factors were noted as significant, it was evident that the plant produced a high quality effluent under current operating conditions and elevated effluent total BOD_5 concentrations were a direct result of partial nitrification of the plant effluent.

3.2.4 Maintenance Factors

With a few exceptions, the facilities visited were well maintained and in a good state of repair. Plant staff generally have a superior knowledge of the requirements for equipment and plant maintenance compared to their knowledge of the requirements for operational process control. Preventative maintenance was often given a higher priority in terms of staff time than operational monitoring. In many cases, chief operators and superintendents originally had a maintenance background. Thus, maintenance factors were seldom noted as factors contributing to the poor historic plant performance. There were three exceptions (Plant C, Plant F and Plant G).

In all three cases, the age or condition of some of the key mechanical or process equipment was considered to contribute to the poor performance of the facility. At Plant C, frequent failure of sludge removal mechanisms in the secondary clarifiers resulted in the loss of solids to the effluent. In addition, maintaining the equipment seriously reduced the amount of time available to undertake process monitoring and impacted on staff morale. (This could also be considered a design problem with the return mechanism.) At Plant G, failure of the return sludge pump and the lack of a backup pump was a problem along with plugging of the aeration equipment. At Plant F, an overall deterioration of the plant's physical condition was noted.

3.2.5 Administrative Factors

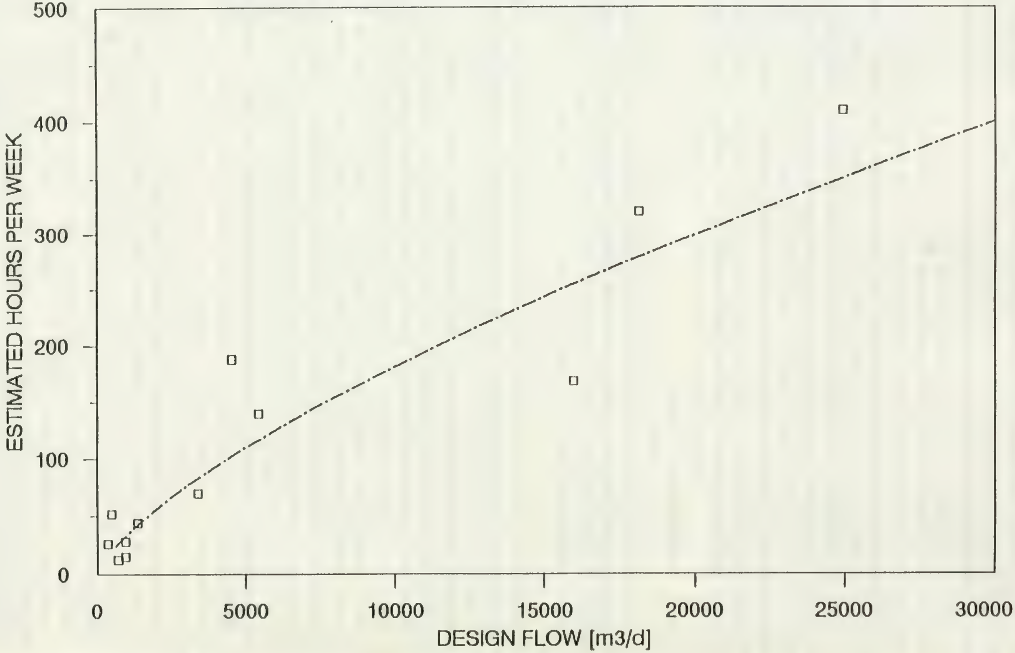
Administrative factors were considered to affect plant performance when decisions made regarding plant design or policies such as these controlling industrial input or wet weather input to the plant directly affected the ability of the plant and the plant staff to operate the facility.

The level of support provided by the plant administrators was identified as a factor contributing to poor performance at ten plants, the third most frequently identified factor. It was also the third most important factor identified. Lack of administrative support was exhibited in a number of different ways. At some plants, lack of control of industrial dischargers precluded effective plant operation. In other plants, extraneous flows in the collection system caused hydraulic loadings under wet weather which could not be effectively handled by the plant. These conditions, which were outside the control of the plant operating staff, directly affected the ability of the facility to perform as designed. Poor management and communication with plant staff was evident at some facilities, leading to poor staff morale. In many cases, any emphasis given to improving plant performance in non-complying plants was through plant expansion or other capital works. Administrators in general did not emphasize optimization or improvement in operation of the existing facility to immediately address apparent effluent quality problems. At only Plant A and Plant K was there apparent administrative support for optimizing plant performance.

The assessment of the adequacy of staffing at these facilities was somewhat subjective. There are no guidelines in Ontario regarding the level of staffing needed for proper operation of municipal STPs. U.S. EPA has developed methods to estimate individual plant staffing needs (38), but these procedures are about 20 years old and may not reflect the improved level of automation in treatment plants nor the increasingly restrictive regulations applied to these facilities. Furthermore, site specific factors can have a significant effect on staffing needs for a particular facility. Figure 12 illustrates the staff person-hours available at the facilities visited as a function of the plant size. These data need to be treated with caution because they do not always consider the availability of other municipal staff to assist with maintenance activities or the use of contract staff to

FIGURE 12

RELATIONSHIP BETWEEN STAFFING AND PLANT DESIGN FLOW



conduct sludge haulage or landscaping activities. It is evident that there is a decrease in plant staffing per unit of design capacity as the design capacity increases. It is also evident that the very small plants (less than 1000 m^3/d capacity) are provided with less than full time operator attention (35 person-hours per week), on average. Based on discussions with plant staff and a review of the operational requirements, inadequate plant staffing was considered to be a factor affecting plant performance at two plants (Plant B and Plant F). At Plant B, there were no resident plant operating staff. The facility was manned from another nearby WPCP and the three staff members were responsible for multiple projects over a wide area. As a result, about two hours per day five days per week were devoted to operating and maintaining Plant B. Similarly, Plant F was staffed by one municipal employee who was also responsible for the water treatment plant, the collection system and pumping station. This resulted in less than half day coverage of the STP, five days per week. At other facilities, limited process monitoring or process testing was conducted but it was not felt that this was a result of inadequate staff to conduct the testing. Rather, it was a lack of priority given to these tasks compared to other tasks.

Financial considerations were felt to affect plant performance at two facilities (Plant A and Plant B). As in other administrative matters, it is often difficult to precisely define the rational behind decisions regarding design or operation of facilities. In one case (Plant A), a low capital cost approach was used to handle high strength industrial wastes which ultimately resulted in an inferior effluent quality. In the other case (Plant B), grit removal equipment was not repaired in an effort to reduce O&M costs. Figure 13 illustrates the relationship between plant flow and O&M costs for treatment. Although only three plants which did not practise phosphorus removal were included in Phase 1 of the study, the lower costs of treatment for these plants is evident from Figure 13. The economies of scale are also evident. Costs per unit treated increase dramatically at treatment capacities less than about 2,200 m^3/d. Figure 14 presents the labour and sludge disposal costs as a percentage of the total O&M costs for plants where this breakdown could be calculated. Detailed cost breakdowns were unavailable for some plants (Plants F and G). At Plant H, no significant sludge disposal costs had been assigned to the facility. Labour costs generally represented between about 25 and 50 percent of the total costs. There was considerable plant-to-plant variation in sludge disposal costs. This variation was due to the relatively small quantities of sludge disposed of at some plants (Plants C, E, H and I) and the relatively inexpensive sludge disposal programs operated at some plants (Plants A and K).

As noted in Section 3.2.3, staff training was not identified as a factor at any of the 12 facilities. Operating staff had taken appropriate training courses and were considered "qualified" to operate their plants. However, in nine of twelve cases, operating staff did not display a fundamental understanding of the operating principals governing their treatment facilities. This has implications with respect to the adequacy of the current methods of delivering training to wastewater treatment plant operating staff.

FIGURE 13

RELATIONSHIP BETWEEN O & M COSTS AND PLANT THROUGHPUT

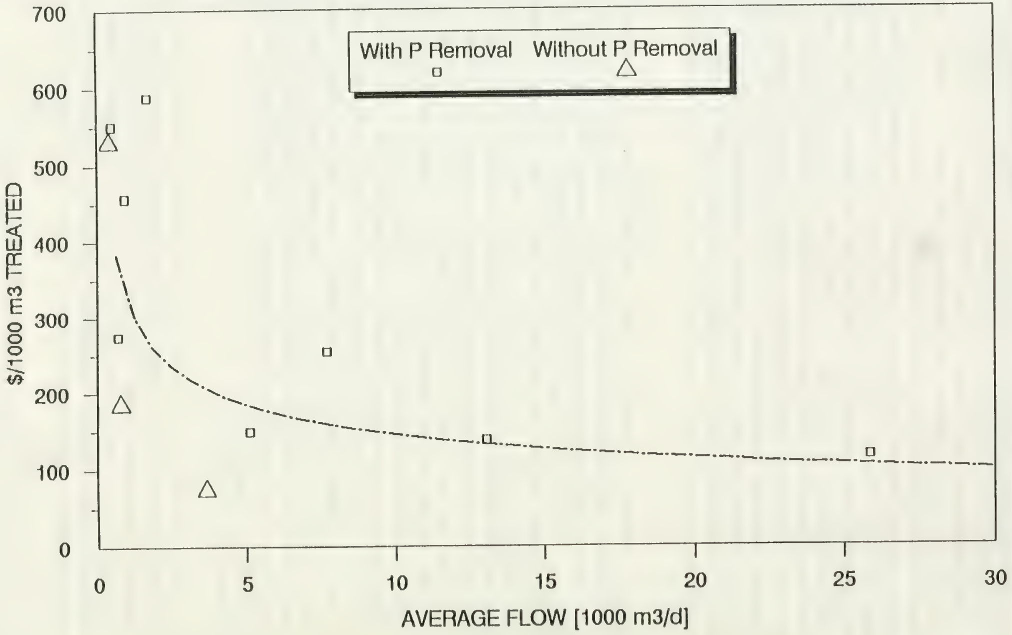
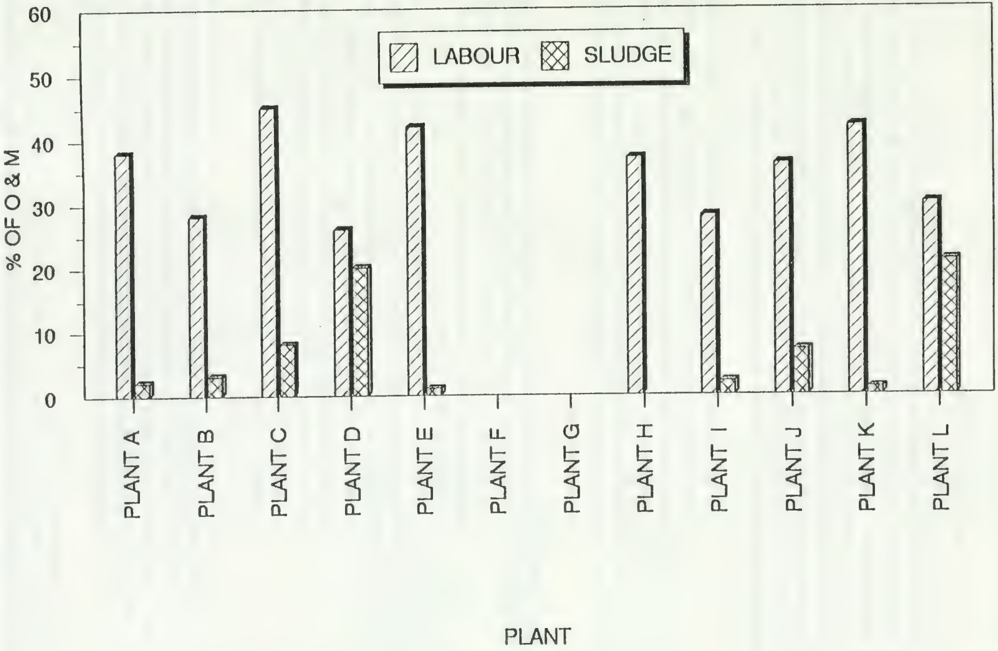


FIGURE 14

LABOUR AND SLUDGE DISPOSAL COSTS AS A PERCENT OF O & M COSTS



3.3 FACTORS IDENTIFIED FROM PROCESS STUDY REPORTS

3.3.1 Crystal Beach WPCP(14)

At the time of the process studies in November-December 1986 and August 1987, the Crystal Beach WPCP was operating at an average daily flow of about 3900 m^3/d compared to a design capacity of 3880 m^3/d and significant quantities of wastewater were bypassing treatment upstream of the plant. Hence, one of the objectives of the process studies was to provide the operating authority with recommendations regarding long-term expansion needs for the facility. At the same time, recommendations were made regarding short-term upgrading of the existing facility. The major findings of the process studies relating directly to limitations in the existing facility were as follows:

- The air lift sludge return system incorporated in the plant resulted in a recycle ratio of about 16:1. This resulted in high solids loadings and excessive sludge inventories in the clarifiers. Under peak flow conditions, solids washout from the clarifiers resulted. There was no metering of return or waste sludge rates and control of RAS was very difficult because of the common wall aeration tank/clarifier configuration and the air lift return system.

- Oxygen transfer capacity in the aerobic digesters limited the amount of sludge which could be wasted from the secondary section of the plant under peak loading conditions in the summer months. The high MLSS concentrations which were maintained as a result aggravated the clarifier operating problems.

- During wet weather periods, significant amounts of wastewater were bypassed around the secondary plant directly to the chlorine contactor. This resulted in a deterioration in final effluent quality and an accumulation of sludge in the contactor which impaired effluent quality during dry weather periods when bypassing was not done. During a six week period in November and December 1986, the amount of flow bypassing secondary treatment equalled about 30 percent of the flow which underwent secondary treatment.

- There was limited process instrumentation for monitoring key parameters controlling the operation of the secondary plant. Excessive air flow rates to the aeration basins, which resulted in DO concentrations of 5 to 7 mg/L, contributed to excessive foam and scum production. Off-line sampling and analysis were also minimal.

3.3.2 Belleville WPCP(15)

The investigations at the Belleville WPCP were designed to develop solutions to bacterial contamination problems in the Bay of Quinte related to the discharges from the facility. Sludge treatment and disposal alternatives and secondary treatment capacity were also evaluated during the process studies conducted in late 1987 and early 1988.

The key findings relating directly to the performance of the existing plant were as follows:

- In order to accommodate high wet weather flows from the collection system, the Belleville WPCP had been expanded from a rated capacity of 36,360 m^3/d to accommodate flows of up to 54,480 m^3/d through secondary treatment and flows up to 108,960 m^3/d through physical chemical treatment. This expansion was accomplished without any increase in aeration basin or secondary clarifier tankage. Thus, design aeration basin hydraulic retention times were only 2 hours and secondary clarifier surface overflow rates were 43.6 $m^3/m^2.d$. Peak day flows of 121,000 m^3/d and instantaneous flows of 165,000 m^3/d were experienced at the plant.

- Sludge disposal deficiencies were a major problem. Sludge had accumulated in the digesters, in sludge holding tanks and in the liquid treatment train due to lack of haulage and insufficient approved land for final disposal. Under peak flow conditions, solids were lost from the process to the plant final effluent. A significant accumulation of solids was evident in the chlorine contactor at the plant.

- Secondary treatment capacity was limited to about 29,500 m^3/d compared to a rated capacity of 54,480 m^3/d due to oxygen transfer limitations in the aeration basins.

- The expansion and re-rating resulted in a complex plant in which it was difficult to accurately measure and control the amount of flow undergoing full secondary treatment and the amount of flow undergoing physical-chemical treatment. Limitations were also noted in the existing WAS and RAS metering equipment which impaired the ability of plant staff to effectively control the inventory of solids in the secondary part of the plant.

3.3.3 Hespeler WPCP(16)

The Hespeler WPCP had a history of non-compliance despite operating at only about 60 percent of its rated capacity. An intensive process evaluation conducted in 1986 identified several major factors which contributed directly to the poor performance of the plant. In this investigation, sludge management problems were not evaluated because a Regional scheme was being implemented to address sludge management problems at all facilities. The major problems identified with the liquid treatment system at the Hespeler WPCP were as follows:

- Although average daily flows at the plant were substantially lower than design, the on/off operation of the plant pumping station resulted in significant flow surges through the plant. These flow surges contributed directly to the high TSS concentrations measured in the plant effluent.

- There were significant differences between air flow rates and liquid flow rates between the two sections of the plant. The air flow problems were compounded by the use of a common air header to supply aeration tanks, aerobic digesters and air lift pumps. High air flow rates to parts of the plant resulted in excessive shear of biological solids. The available instrumentation in the plant was inadequate to allow the operators to control return rates, wastage rates or air flow rates within the plant.

- Significantly different solids inventories were maintained in the two halves of the secondary plant. The monitoring program applied was inadequate to ensure that the MLSS concentrations were controlled at appropriate levels.

- Nickel and zinc concentrations in sludges often exceeded guidelines for land disposal because of industrial discharges. There was no contingency plan in place to deal with sludges which could not be land disposed. Occasional upsets of the biological processes due to heavy metal discharges were also evident.

3.3.4 Toronto Highland Creek WPCP(17)

The objective of the investigations undertaken at the Highland Creek WPCP in 1989 was to determine the possible human health effects of the plant on the surrounding community. Hence, the process analyses undertaken at this facility were less intensive than those conducted at the other six plants. However, a review of available design, operation and performance information was included in the environmental audit. This review did identify some specific factors affecting the plant performance, including:

- The limited capacity of the sludge treatment and disposal processes (anaerobic digestion, DAF thickening, thermal conditioning, centrifugal dewatering and incineration) necessitated the storage of excess solids within the liquid treatment trains. Primary clarifiers were used for sludge storage and high solids inventories were maintained in parts of the secondary portion of the plant.

- Because of the high solids inventory maintained in parts of the plant, the low removal efficiency of the primary clarifiers and the design of the aeration basins and oxygen transfer equipment, low dissolved oxygen concentrations are experienced in parts of the secondary treatment plant. There is little flexibility in the plant design to accommodate operating approaches other than complete-mix conventional activated sludge.

- There was extensive automated data logging capability within the plant. However, the complexity of both the liquid and sludge management trains would benefit from more sophisticated on-line monitoring and control of key process variables such as dissolved oxygen concentration and sludge wastage.

- Extensive process sampling and monitoring was conducted at the plant to support process control actions. However, the data reporting system was not conducive to evaluation of the condition of the individual parts of the plant because results were logged into a generic operating report which was not tailored to the process flowscheme used at the Highland Creek plant.

3.3.5 Corbett Creek WPCP(18)

Despite operating at less than design average flow, the Corbett Creek WPCP had difficulty achieving its performance objectives. High effluent total phosphorus concentrations were the primary symptom of performance difficulties, but elevated effluent BOD_5 and TSS concentrations were also experienced. A process study was conducted between July and November 1989 with the objective of identifying approaches to optimize the performance of the existing facility. A number of performance problems were identified as a result of these investigations, including the following:

- The Corbett Creek WPCP received substantial quantities of industrial wastewater flow. These discharges resulted in elevated and highly variable concentrations of BOD_5, TSS and TP in the raw sewage received at the plant.

- Oxygen transfer limitations were noted in part of the secondary treatment plant where the two speed aeration hardware could not be operated at the higher speed without encountering mixing problems.

- Shortcircuiting in some of the secondary clarifiers and the high-rate plant aeration basins was identified.

- The existing instrumentation at the plant did not allow an accurate measure of the influent flowrate, the flow split between the secondary treatment plants, the individual plant return sludge rates, the wastage rates or other key process variables controlling plant performance. There was limited flexibility to control the flow to different parts of the plant because of the lack of instrumentation and the minimal differential head through the plant.

- Extensive in-plant operational and performance monitoring was conducted, but this information did not allow plant staff to determine separately the performance of the individual parts of the plant.

3.3.6 Duffin Creek WPCP(19)

The Duffin Creek WPCP was operating at more than 90 percent of its design capacity and further substantial increases in flow were expected before a planned expansion was completed. Process studies were done between July and November 1989 to identify means to optimize plant performance in the immediate term. As a result of these studies, several factors were identified as having a significant impact on plant performance, including the following:

- At flows in excess of 1.5 times the design capacity, the mechanical aeration equipment was automatically shut-off because of high power draws caused by the increased water level in the aeration basins. A significant deterioration in effluent quality occurred when the aeration equipment was shut down.
- Sludge treatment and disposal capacity was limited by the volume of the primary digesters. The problem was compounded by poor mixing in the existing digesters. Because of sludge treatment limitations, high solids inventories were carried in the secondary part of the plant and primary clarifiers were used for excess sludge storage.
- Considerable short circuiting of the secondary clarifiers was identified based on the results of dye testing studies.
- Deficiencies with raw sewage flow metering and RAS metering were noted. In addition, there was no capability to measure the flow split between individual sections of the plant although it was suspected that there were flow splitting difficulties.

3.3.7 Burlington Skyway WPCP(20)

There was no history of compliance difficulties at the Skyway WPCP. The goals of the process studies undertaken at the plant between September 1990 and March 1991 were to determine plant capacity and to identify expansion requirements for the plant to meet future growth and expected more stringent effluent quality requirements. These studies did, however, identify performance difficulties at the facility including the following:

- Serious flow distribution problems between the twelve secondary clarifiers were identified. The flow distribution problem was compounded by short circuiting in the clarifiers which impaired the overall performance of these units.
- Sludge settleability problems were identified due to the proliferation of filamentous organisms in the plant. Poor settling characteristics in conjunction with the flow distribution and short-circuiting problems further detracted from the performance of the secondary clarifiers.
- Low dissolved oxygen concentrations were noted in the aeration basins. These low DO levels may have contributed to the proliferation of filamentous organisms in the plant.
- A review of the waste sludge data for the plant suggested that the wastage rate was variable and that there were metering problems which resulted in an overestimate of the amount of sludge removed from the process.

RAS metering and control problems from the individual clarifiers were also noted.

3.3.8 Summary of Factors Identified in Process Study Reports

The effect of each of the 25 factors listed in Table 5 on the performance of these seven STPs was evaluated. As was done at the 12 plants visited, each factor was rated as an "A", "B" or "C" factor and ranked in terms of its relative importance at each plant. The results of this analysis are summarized in Figures 15, 16 and 17 in terms of the frequency at which each factor was identified at the seven plants and the relative importance of each factor. The ten most frequently identified factors and those which contributed most significantly to performance problems are identified in Table 11. As noted in Section 2.4.3, the process study reports did not always contain adequate data to assess the sludge management process design and administrative factors. Hence, the evaluation of the impacts of these factors on plant performance was not always as comprehensive as was possible for the 12 plants where site visits were undertaken.

In general, fewer factors were identified as contributors at these seven plants than at the 12 plants visited. Design factors were more often identified in the process study reports than operational or administrative problems because the objectives of the process studies were focused on a design analysis. Of the ten most frequently identified and most important factors, five were related to the design of the liquid process units and two were related to the design of the sludge process units. Three operational factors were noted frequently and one administrative factor. Equipment maintenance problems were not noted as factors contributing to poor performance at any of the seven facilities.

Limitations in the available instrumentation and control equipment was noted at all seven facilities as it had been at all twelve STPs visited in this phase of the study (Table 6). In all except one plant, the effects on performance were minor on a continuous basis ("C" factor). Hence, instrumentation and control equipment was only the fifth most important factor at the seven plants. It appears that even the generally larger plants which were the subject of the seven process study reports did not have adequate instrumentation and control equipment to provide the operating staff with key information needed for effective process control.

Limitations in oxygen transfer capacity were noted in six of the seven plants. This was the second or third most important factor in terms of its effects on plant performance. Oxygen transfer limitations had only been noted at three of the 12 facilities visited, but appeared as a much more significant problem based on the findings of the process study reports. Measurement of oxygen transfer capacity was a key element of all of the process studies with the exception of the Highland Creek WPCP audit. Thus, far more detailed information was available in these reports on which to assess the efficiency of the oxygen transfer capacity equipment and the oxygen demand than was available from the site visits where oxygen transfer was based on the estimated transfer efficiency of the aeration hardware. Actual field measurement of oxygen transfer capacity and oxygen demand might indicate that it is more of a problem than it seems based on the 'desk-top' analysis done at the other 12 plants.

FIGURE 15

FREQUENCY OF OCCURENCE OF PERFORMANCE LIMITING FACTORS
FROM PROCESS STUDY REPORTS

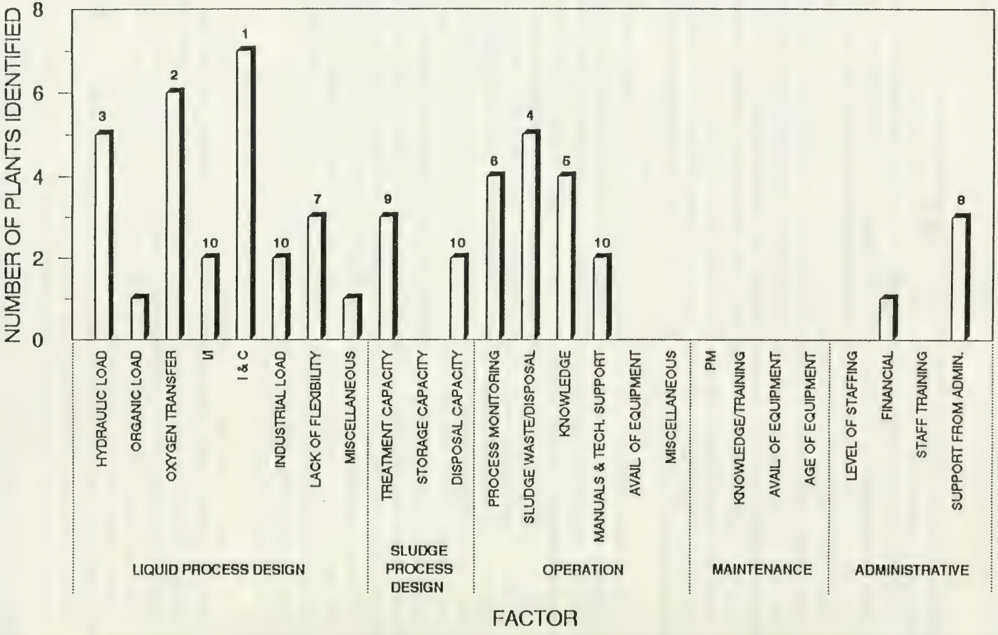


FIGURE 16

FREQUENCY RATING OF PERFORMANCE LIMITING FACTORS
FROM PROCESS STUDY REPORTS

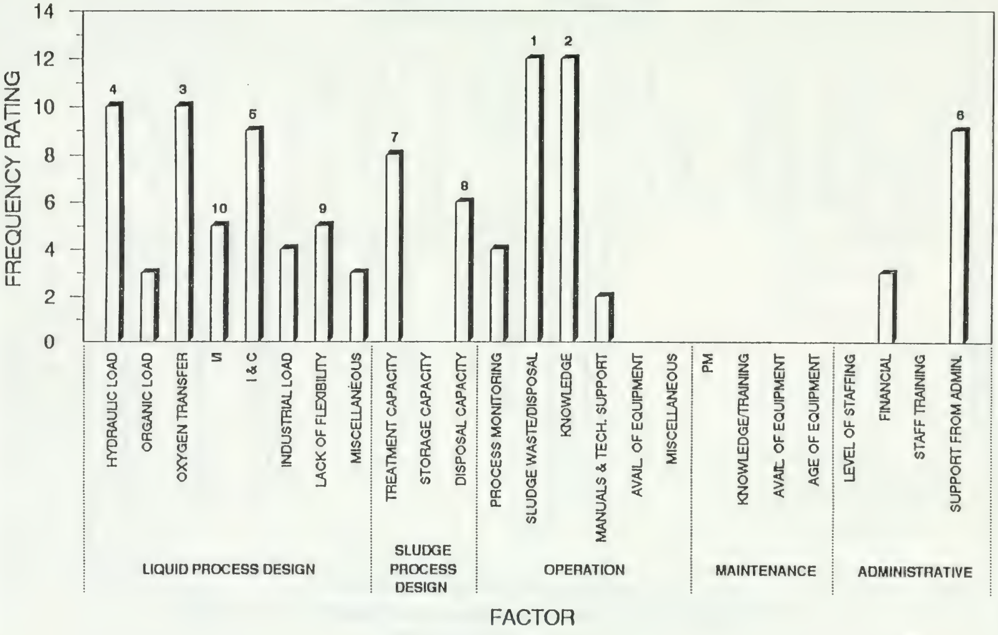


FIGURE 17

IMPORTANCE RATING OF FACTORS LIMITING PERFORMANCE
FROM PROCESS STUDY REPORT

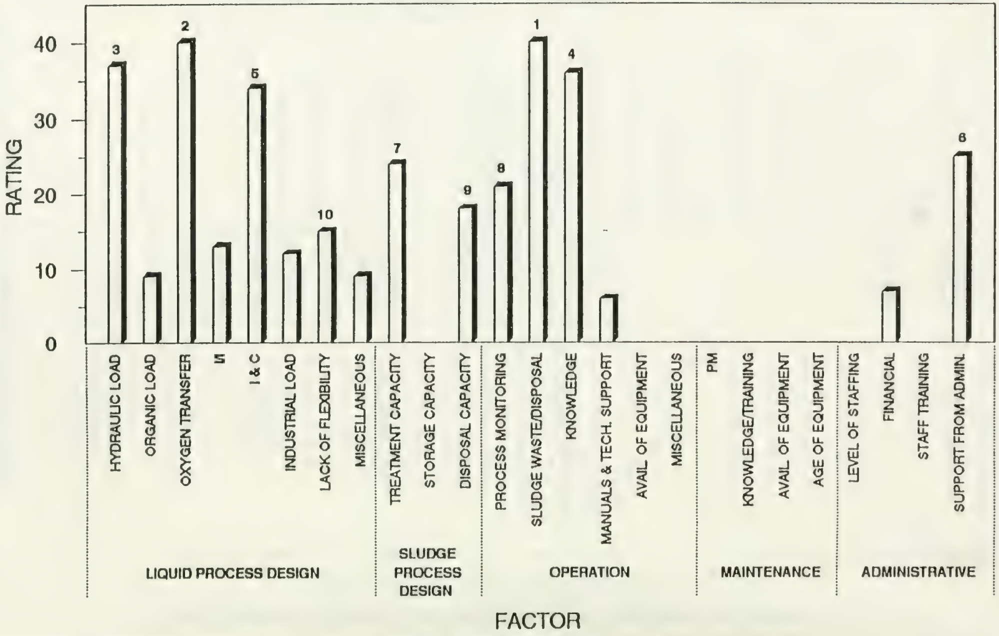


TABLE 11

SUMMARY OF MOST IMPORTANT FACTORS AFFECTING PERFORMANCE OF STPs SUBJECTED TO PROCESS STUDIES

	Rank			
Factor	Frequency	Frequency Rating	Importance Rating	Nature of Problem
Instrumentation and Control	1	5	5	Design - Liquid Units
Oxygen Transfer	2	3	2	Design - Liquid Units
Hydraulic Loading	3	4	3	Design - Liquid Units
Sludge Wastage and Disposal	4	1	1	Operational
Knowledge of Wastewater Treatment Principles	5	2	4	Operational
Process Monitoring	6	NR	8	Operational
Lack of Flexibility	7	9	10	Design - Liquid Units
Support from Administrators	8	6	6	Administrative
Sludge Treatment Capacity	9	7	7	Design - Sludge Units
Extraneous Flow (I/I)	10*	10	NR	Design - Liquid Units
Sludge Disposal Capacity	10*	8	9	Design - Sludge Units

* Two other factors (Industrial Input and Manuals & Technical Support) were also noted at two STPs, tying for tenth in terms of frequency of occurrence.

NR = Not Ranked

Hydraulic loading was noted at five of the seven plants, the third most frequently identified factor. However, in this case, it was not frequently identified in conjunction with extraneous flows in the collection system. This was noted at only two plants. As was the case with oxygen transfer, the process studies focused specific attention on identifying hydraulic problems such as short-circuiting in clarifiers which can affect performance at flows substantially below design. The on/off operation of a plant pumping station was found to directly affect plant performance at one facility although the plant was operating at substantially below design loading. This problem was noted at several of the 12 STPs visited (Figure 7).

Lack of flexibility in the liquid treatment train was noted as a factor at three plants. This had only been noted as significant at two of the other twelve plants visited. The difference in importance placed on flexibility of plant operation may reflect the improved ability to assess the benefits of other operating schemes based on detailed process studies in the plant compared to 'desk-top' analysis of the plant.

Limitations in the sludge treatment and disposal capacity were identified as factors at three plants and two plants, respectively. It is noteworthy that neither of these factors was noted with any frequency at the other 12 plants. However, sludge storage capacity limitations, noted at five of the other 12 plants, was not identified as a problem area at any of these seven plants. Two of the seven plants incinerated sludge and storage capacity was not a factor. Three had extensive off-site storage available to alleviate problems with their land utilization programs. (Note: The sludge management system at the Hespeler WPCP was not evaluated during the process studies undertaken at that plant.)

Inadequate control of the solids inventory in the plant through adequate sludge wastage and disposal was noted at five plants. It was the most important factor contributing to poor performance overall at these seven facilities. This supports the findings of the 12 plant visits (Table 9) where this factor was also found to be the most important contributor to poor plant performance. The inability to maintain solids inventory control in the biological system, either because of capacity limitations or a lack of appreciation on the part of the operators regarding the importance of solids inventory control, will ultimately lead to the failure of the treatment process.

Lack of demonstrated knowledge of plant staff regarding the application of key principles of plant operation to their facilities, the other operational factor noted with some frequency (four plants out of seven), was often closely related to the lack of an adequate solids inventory control program or to the lack of adequate process monitoring to support fundamental process control decisions. The latter was identified as a factor at four plants, but was not as significant a factor in terms of its contribution to poor performance as the other two operational factors.

As noted in Section 2.4.3, there was little emphasis on administrative matters in the process reports. Hence, it was more difficult to assess the relative importance of these factors to the performance of the plant. Despite this limitation, administrative support to plant operating staff was felt to contribute to poor plant performance at three plants based on the information in the process study report. Generally, this was demonstrated by the lack of adequate control of industrial discharges into the plant, the lack of a timely expansion plan for the plant to address known capacity limitations or the lack of emphasis on solving apparent operating problems in order to bring the plant into compliance.

3.4 SUMMARY OF FACTORS CONTRIBUTING TO POOR PERFORMANCE

3.4.1 Comparison of Findings of Site Visits and Process Study Reports

Table 12 compares the ten most frequently identified factors based on the 12 plants visited in this phase of the study and the seven plants for which process study reports were available. There are noteworthy similarities in the findings as well as noticeable differences.

Of the ten most frequently noted factors among the 12 plants visited, nine were included among the ten most frequently noted factors based on the process study reports. Inadequate instrumentation and control (I&C) equipment was the most commonly identified factor in both parts of the analysis. Of the five most commonly noted in the 12 plants, three (I&C, sludge wastage and disposal, and knowledge of wastewater treatment principles) were among the top five factors based on the process studies.

From the process study reports, four factors (oxygen transfer, lack of flexibility, sludge treatment capacity and sludge disposal capacity) were noted frequently which had not been identified frequently in the 12 plants visited. In the case of the sludge design factors (treatment and disposal), this may reflect differences in the ultimate disposal methodologies used at the generally larger plants included among the seven for which process reports were available. In the case of the liquid unit design factors (oxygen transfer and lack of flexibility), it may reflect better information which can be obtained from intensive process studies compared to 'desk-top' analysis as well as the greater emphasis placed on liquid process unit design in this studies.

Table 13 compares the factors identified as the most significant contributors to performance problems from the two groups of plants. In terms of importance, significant similarities and differences exist. In both groups of plants, the most important factor affecting plant performance was inadequate removal of excess sludge from the plant. Lack of demonstrated ability among operating staff to apply the fundamental principles of wastewater treatment ranked high in both groups of plants, as did hydraulic loading. However, extraneous flow was a lesser factor among the plants where process studies were done than among the visited plants. The degree of support supplied by plant administrators to the operating staff was an important factor influencing performance in both cases.

3.4.2 Summary of Overall Findings

The frequency and importance rating of each of the 25 factors from the 12 STPs visited and the seven STPs at which process studies were conducted were compiled together to provide an overall frequency and importance rating. The results of this compilation are

TABLE 12

COMPARISON OF TEN MOST FREQUENTLY IDENTIFIED FACTORS BETWEEN VISITED AND STUDIED FACILITIES

Factor	Rank for Visited Plants	Rank for Studied Plants
Instrumentation and Control	1	1
Sludge Wastage and Disposal	2	4
Support from Administrators	3	8
Knowledge of Wastewater Treatment Principles	4	5
Manuals and Technical Support	5	10
Extraneous Flow (I/I)	6	10
Hydraulic Loading	7	3
Process Monitoring	8	6
Industrial Input	9	10
Sludge Storage Capacity	10	NR
Oxygen Transfer	13	2
Lack of Flexibility	16	7
Sludge Treatment Capacity	NR	9
Sludge Disposal Capacity	20	10

NR = Not Recorded

TABLE 13

COMPARISON OF TEN MOST IMPORTANT FACTORS AFFECTING PERFORMANCE AT VISITED AND STUDIED PLANTS

	Visited Plants		Studied Plants	
Factor	Frequency Rating	Importance Rating	Frequency Rating	Importance Rating
Sludge Wastage and Disposal	1	1	1	1
Knowledge of Wastewater Treatment Principles	2	2	2	4
Support from Administrators	3	3	6	6
Extraneous Flow (I/I)	5	4	10	11
Hydraulic Loading	4	5	4	3
Process Monitoring	6	6	11	8
Instrumentation and Control	7	7	5	5
Manuals and Technical Support	9	8	16	16
Industrial Input	8	9	11	12
Sludge Storage Capacity	10	10	NR	NR
Oxygen Transfer	16	13	3	2
Sludge Treatment Capacity	NR	NR	7	7
Sludge Disposal Capacity	19	19	8	9
Lack of Flexibility	20	20	9	10

NR = Not Recorded

presented in Figure 18 (frequency of occurrence), Figure 19 (frequency rating) and Figure 20 (importance rating).

The ten most frequently identified factors contributing to poor performance are listed in Table 14. Comparison of the factors noted frequently in all 19 plants with those identified frequently in the visited plants (Table 9) shows that nine of ten factors appear on both lists and the frequency and importance rankings are very similar. The one factor which appears in Table 14 which was not included in Table 9 is "oxygen transfer limitations", a problem noted at many of the facilities which had undergone extensive process studies.

Of the ten factors noted commonly and with a high degree of importance, five relate to the design of the liquid treatment units, four are operational and one is administrative. No factors related to maintenance or to the design of the sludge treatment unit processes are included among those listed in Table 14, although the inadequate control of sludge wastage and disposal may be related in some cases to the lack of available sludge treatment, storage or disposal capacity. This factor--the inadequate control of the sludge inventory maintained in the plant--was the most important contributor to poor plant performance. It was often a direct result of the apparent lack of knowledge of wastewater treatment principles displayed by operating staff which resulted in the lack of control of the biomass inventory. This lack of demonstrated knowledge of plant operating principles was the second most important factor limiting plant performance.

Lack of support by administrators to plant operating staff was the third most important factor overall. This lack of support was displayed in a variety of ways, including lack of attention to apparent operating problems to determine the cause and recommend solutions to improve performance, lack of regulation of industrial dischargers, lack of support to sludge utilization programs, or lack of control of extraneous flows into the collection system.

Hydraulic loading was the fourth most significant factor identified, often as a direct result of extraneous flow into the collection system (the fifth or sixth most important factor). However, as noted in Section 3.2.1, the design of raw sewage pumping stations often compounded the hydraulic loading problems at these facilities. A direct relationship between elevated effluent TSS concentrations and hydraulic disturbances created by pump cycles has been established based on on-line STP process audit data (16).

The lack of adequate instrumentation and control equipment, process monitoring and available manuals and technical support were frequently encountered problems which generally had a more minor effect on the plant performance on an on-going basis than the other factors noted above.

Limitations in oxygen transfer capacity and the effects of industrial loading were less frequently identified as problem areas, but often had a major impact on plant performance in plants where they were identified as factors.

FIGURE 18

FREQUENCY OF OCCURENCE OF PERFORMANCE LIMITING FACTORS AT ALL STPs

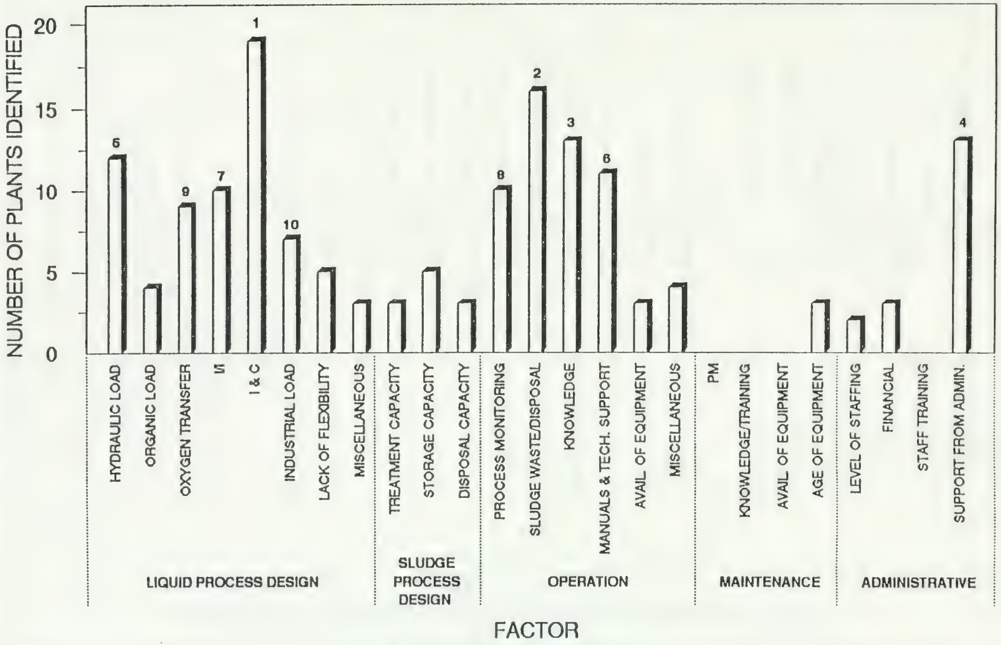


FIGURE 19

FREQUENCY RATING OF PERFORMANCE LIMITING FACTORS
AT ALL STPs

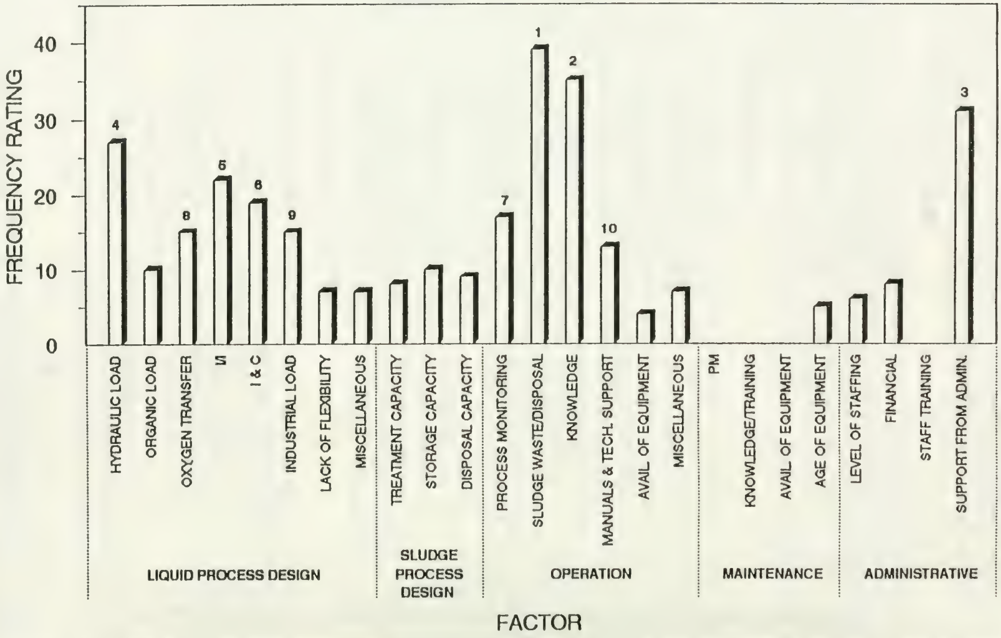


FIGURE 20

IMPORTANCE RATING OF FACTORS LIMITING PERFORMANCE AT ALL STPs

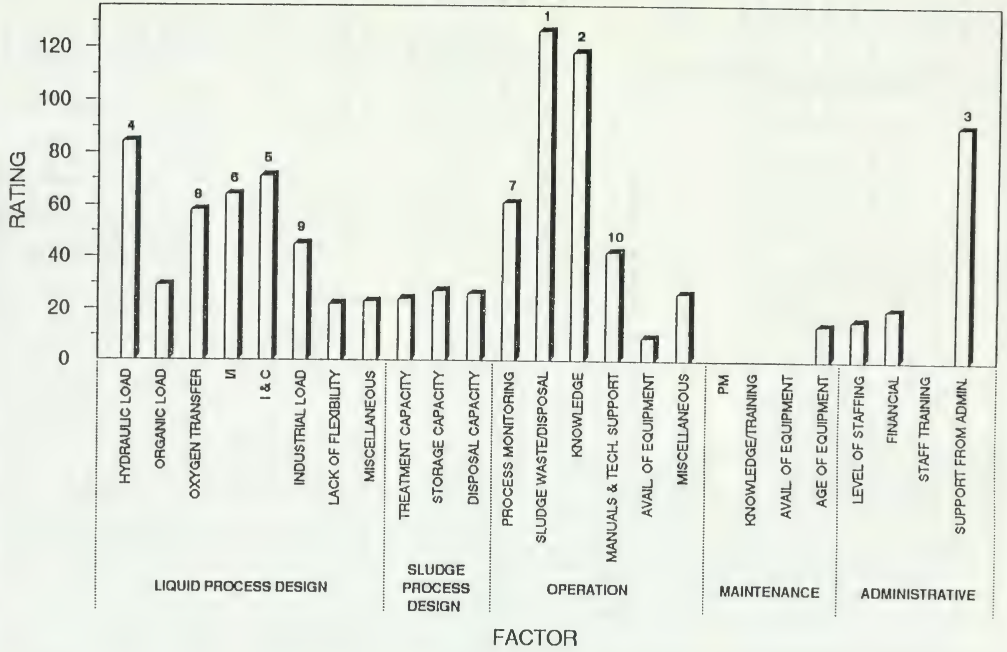


TABLE 14

TEN MOST FREQUENT AND MOST IMPORTANT FACTORS AFFECTING PERFORMANCE AT ALL FACILITIES

	Rank			
Factor	Frequency	Frequency Rating	Importance Rating	Nature of Problem
Instrumentation and Control	1	6	5	Liquid Process Design
Sludge Wastage and Disposal	2	1	1	Operational
Knowledge of Wastewater Treatment Principles	3	2	2	Operational
Support from Administrators	4	3	3	Administrative
Hydraulic Loading	5	4	4	Liquid Process Design
Manuals & Technical Support	6	10	10	Operational
Extraneous Flow (I/I)	7	5	6	Liquid Process Design
Process Monitoring	8	7	7	Operational
Oxygen Transfer	9	8	8	Liquid Process Design
Industrial Loading	10	9	9	Liquid Process Design

3.4.3 Comparison of Findings with Other STP Assessments

A survey of Ontario STPs was conducted in the early 1970's (41) to identify commonly encountered problem areas. This analysis was based on the responses to a questionnaire received from 151 mechanical plants in the province. From this survey, it was identified that hydraulic overloading was the major problem area in STP operation and performance. It was also noted that "equipment performance, maintenance and reliability" were not significant problems but that additional flow measuring equipment would be desirable. These conclusions support the findings of this study in which maintenance was not found to be a factor, instrumentation and control equipment was generally inadequate particularly in the area of RAS and WAS metering, and hydraulic loading was the most important liquid treatment unit process design factor affecting performance.

Two recommendations from the earlier survey are pertinent to the findings of this study, namely:

1. "Some minimum requirements for plant staffing and hours of supervision should be introduced to ensure continuous adequate operation."

2. "The continuous expansion and development of operator training programmes is recommended."

These recommendations were made in part to address the observation that there was often inadequate process testing performed at these facilities to ensure optimum performance. Lack of knowledge of plant operators regarding fundamental wastewater treatment plant principles and inadequate process monitoring are still in evidence in Ontario STPs based on the results of this study.

The most comprehensive recent survey of factors affecting the performance of municipal treatment facilities was the East-West Study described in Section 1.0 of the report (2,3,4). Table 15 lists the ten most commonly identified factors in the East Study and in Phases 1 and 2 of the West Study and compares them with the findings of this investigation. While there are some differences in the factors listed based on the U.S. experience and the findings of this study, there are noteworthy areas of agreement.

All phases of the East-West Study concluded that the most significant problem encountered in American municipal sewage treatment plants was that the operating staff were deficient in the application of their knowledge of wastewater treatment and the interpretation of process control testing such that improper process control adjustments were made in their plants. Related areas associated with the knowledge base available to operations staff such as inadequate process control testing, inadequate O&M manuals, insufficient training, lack of basic understanding and poor technical guidance were also noted as significant factors affecting plant performance. These or similar factors were identified in the Ontario STPs as among the ten most significant contributors to poor performance. The level of knowledge displayed by plant operations staff regarding fundamental wastewater treatment plant operating concepts was the second most important factor after inadequate sludge wastage and disposal. Inadequate process

TABLE 15

COMPARISON TO OTHER
STUDY RESULTS
(TEN MOST IMPORTANT* PROBLEMS)

East Study(7)		West Study - Phase 1(3)		West Study - Phase 2(4)		This Study	
Factor	Nature of Problem	Factor	Nature of Problem	Factor	Nature of Problem	Factor	Nature of Problem
Operator Application of Concepts to Process Control	Operation	Operator Application of Concepts and Testing to Process Control	Operation	Operator Application of Concepts and Testing to Process Control	Operation	Sludge Wastage and Disposal	Operation
Infiltration/Inflow	Design	Sewage Treatment Understanding	Operation	Infiltration/Inflow	Design	Knowledge of Wastewater Treatment Principles	Operation
Process Control Testing	Operation	Technical Guidance	Operation	Sludge Wasting Capability	Design	Support from Administrators	Administrative
O&M Manual Adequacy	Operation	Process Control Testing	Operation	Technical Guidance	Operation	Hydraulic Loading	Design
Industrial Loading	Design	Sludge Wasting Capability	Design	Process Controllability	Design	Instrumentation and Control	Design
Training	Operation	Process Flexibility	Design	Aerator	Design	Extraneous Flow (I/I)	Design
Hydraulic Loading	Design	Process Controllability	Design	Sewage Treatment Understanding	Operation	Process Monitoring	Operation
Treatment Understanding	Operation	Clarifier	Design	Process Control Testing	Operation	Oxygen Transfer	Design
Process Controllability	Design	Sludge Treatment	Design	Process Flexibility	Design	Industrial Loading	Design
Sludge Treatment	Design	Aerator	Design	Ultimate Sludge Disposal	Design	Manuals & Technical Support	Operation

* Ranked in decreasing order in terms of importance to plant performance.

monitoring and inadequate manuals and technical support were also among the ten most significant factors. In some cases, the inadequate control of sludge wastage and disposal was a result of the lack of application of wastewater treatment plant principles to plant operation.

Hydraulic loading and/or extraneous flow (I/I) problems were noted in the East Study and in Phase 2 of the West Study, but had been specifically excluded in Phase 1 of the West Study. Both factors were noted as significantly affecting plant performance in Ontario STPs. Limitations with the "aerators" were noted in both phases of the West study. Oxygen transfer limitations were noted in the Ontario plants, primarily those where process studies had been conducted. Industrial loading was noted in the eastern plants surveyed and in the Ontario plants.

Inadequate instrumentation and control was noted at all Ontario plants. This specific factor was not evaluated in the East-West Study; however, lack of process controllability and flexibility were noted as factors in these studies generally due to the lack of available measurement and control equipment in the plants.

The major difference between the factors noted in the U.S. plants and the Ontario plants was that lack of support from plant administrators was noted as a very significant factor in the Ontario plants but no administrative factor was included in the top ten factors in any part of the East-West Study. This may reflect the increased emphasis placed at the Federal level in the US on industrial pretreatment and extraneous flow control, the "dual" jurisdiction of MOE and the municipality in the collection system and treatment plant in many Ontario STPs or may merely represent a difference in the way that these factors were evaluated in the different studies.

3.5 EFFECT OF LIMITING BYPASS AND REQUIRING NITRIFICATION ON STP COMPLIANCE

3.5.1 Bypassing Restrictions

The MISA programme may restrict bypassing of raw sewage at STPs under wet weather flow conditions. As part of this phase of the investigation, an attempt was made to assess the possible impacts of this restriction on the 12 STPs visited. Possible means to mitigate the effects of bypass flows on these plants were suggested. The costs of implementing bypass flow monitoring at plants which experience bypassing but do not currently have bypass flow monitoring capabilities were estimated. Table 16 summarizes available information on bypassing from the 12 STPs under consideration. These data apply to the main plant pumping station (if applicable) and the treatment plant only. At some facilities, there are combined sewer overflows (Plant A) or emergency high level overflows at satellite pumping stations within the collection system. Generally, there were no data available regarding the frequency of occurrence or the quantity of overflow at these locations. The exception is Plant J where a high level overflow exists at a manhole outside of the plant boundary and there is no overflow at the plant. In this case, available information regarding this off-site overflow location is included in Table 16.

TABLE 16

SUMMARY OF BYPASS INFORMATION

	Plant A	Plant B	Plant C	Plant D	Plant E	Plant F	Plant G	Plant H	Plant I	Plant J	Plant K	Plant L
Total Treatment Plant Bypass	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Locations	P/S	P/S & H/W	P/S & H/W	P/S & H/W	H/W	H/W	H/W	H/W	P/S & H/W	manhole outside plant	P/S & H/W	P/S
Means Initiated	Automatic	P/S - manual H/W - manual	P/S - Automatic H/W - Automatic	P/S - Automatic H/W - Manual	Automatic	Automatic	Automatic	Manual	P/S - Automatic H/W - Manual	Automatic	P/S - Automatic H/W - Manual	Automatic
Occurrence	0 **	P/S - 0 H/W - 10	P/S - 782 Days H/W - N.A.	P/S - 0 *** H/W - 0	0	9 events in 1990	N.A.	216 hrs. in 1987 & 1989	P/S - N.A. H/W - 0	N.A.	P/S - 0 H/W - 0	N.A.
Estimated Quantity	0	P/S - 0 H/W - N/A	P/W - 162 x 10^3m^3 for 1988-1990 H/W - N.A.	P/S - 0 H/W - N/A	0	8.8 x 10^3m^3 in 1990	N.A.	2.7 x 10^3m^3 in 1987 and 1989	P/S - N.A. H/W - 0	N.A.	P/S - 0 H/W - 0	N.A.
Flow Metering	YES	P/S - NO H/W - NO	P/S - YES (1988) H/W - NO	P/S - NO H/W - NO	YES	YES	NO	NO	P/S - NO H/W - NO	NO	P/S - NO H/W - NO	NO
Severity of Bypassing	No Bypassing	P/S - not used H/W - under extreme flow conditions	P/S - Flow in excess of $11,365m^3/d$ H/W - flows between 6,656-11,365 $m^3/3$	P/S - not used H/W - under extreme flow conditions	Flows in excess of 13,638 m^3	Flows in excess of 2724 m^3/d	N.A.	Initiated under extreme flow conditions	P/S - N.A. H/W - not used	N.A.	No Bypassing	Bypass in event of power failure
Included in Sampled Effluent	NO	P/S - NO H/W - YES	P/S - NO H/W - YES	P/S - NO H/W - YES	YES	NO	NO	NO	P/S - NO H/W - YES	NO	P/S - NO H/W - YES	NO
Secondary * Treatment Bypass	YES	N/A	N/A	N/A	N/A	YES	N/A	N/A	N/A	NO	N/A	YES
Flow Metering	YES	N/A	N/A	N/A	N/A	NO	N/A	N/A	N/A	N/A	N/A	NO
Included in Sampled Effluent	YES	N/A	N/A	N/A	N/A	YES	N/A	N/A	N/A	N/A	N/A	NO

* Refers to bypass capability after primary treatment
** Excludes any bypassing or CSO in collection system
*** Based on past two years

N/A = Not Applicable
P/S = Pumping Station
N.A. = Not Available
H/W = Headworks

All of these facilities have the capability to bypass raw sewage either at the headworks or at the plant pumping station or both under emergency situations or at peak flow to protect the downstream processes from washout. At two plants (Plant B and Plant H), any bypassing must be manually initiated. At seven plants, bypassing will occur automatically via a high level overflow at the headworks and/or at the plant pumping station. Three plants (Plants D, I and K) are equipped with automatic emergency overflows at the plant pumping station as well as manually activated overflows at the plant headworks.

Three of the four conventional activated sludge plants (Plants A, F and L) have the capabilities to bypass after primary treatment to protect the secondary portion of the plant. At Plant A, excess primary treated effluent is automatically discharged to the polishing lagoons where it is mixed with secondary treated effluent prior to disinfection and discharge. At Plant F, excessive primary effluent flow is manually diverted to the chlorine contactor for disinfection before discharge.

Five of these STPs (Plants A, E, I, K and L) had not bypassed any raw sewage at the STP during the five year period from 1986 to 1990. Hence, at these facilities, restrictions on raw sewage bypassing would have no impact on the plant performance.

The other seven STPs (Plants B, C, D, F, G, H, J) have experienced some bypassing of raw sewage over this five year period. At all seven facilities, with the exception of Plant D which did not have a bypass event in the past two years, the subjective impression is that bypassing occurs with significant frequency (at least ten times per year under wet weather or stormflow conditions). However, the data available regarding the frequency of occurrence and the quantity of bypass flow are very limited.

At three plants (Plants B, D and H), the bypass is manually initiated by plant staff to prevent washout of the process. In these cases, there are records of the frequency and duration of bypassing. However, only one of these plants (Plant H) estimated the bypass flow quantity. At this plant, it is assumed that half of the raw sewage flow is bypassed when bypass is initiated because of the configuration of the headworks at the bypass location.

Of the four plants where raw sewage bypass is initiated automatically through an overflow structure, two plants (Plants G and J) have no record of the frequency, duration or amount of bypassed flow. One plant (Plant C) has flow metering capability on the automatic bypass at the pumping station but does not have metering capability for flows bypassed at the headworks. Hence only a partial record of the amount of raw sewage bypass is available. One plant (Plant F) has metering capability for raw sewage bypass flows; however, due to equipment problems, records of bypassing are very limited. Some data are available for 1990 for this facility.

Of the six facilities (Plants B, C, F, G, H and J) which experience raw sewage bypassing with some frequency, only Plant B would include all bypassed flow in their final effluent sample if that sample were collected at the time that bypassing was occurring. Plant C would include bypass flows from the headworks but not from the pumping station. Hence, final effluent quality from Plants C, F, G, H and J will be poorer than suggested by the recorded performance data under wet weather conditions when bypassing is occurring.

Because of the lack of data on quantities and frequency of bypassing at these facilities, it is only possible to identify those plants where restricting bypass may affect plant performance and those plants where there will not likely be an impact. The magnitude of the impact on plant performance cannot be predicted because the extent of the flow problem is not known. Similarly, possible options to mitigate the effect can be identified based simply on the configuration of the plant. The feasibility of successfully implementing any particular option and its cost effectiveness requires additional information regarding the quantity and frequency of bypass flow. This information is summarized in Table 17. As summarized in Table 17, half of the 12 STPs (Plants A, D, E, I, K and L) under consideration are unlikely to be impacted by restrictions on raw sewage bypass based on the available data. The other six facilities will be affected, but the extent of the impact cannot be determined without additional information regarding the frequency, duration and magnitude of the bypass events.

The development of cost estimates for installing flow metering devices on bypass flows not currently metered at these facilities is also limited by the lack of data concerning the magnitude of the flow. Costs were developed based on installing overflow weirs or flumes in pump station and bypass channels along with ultrasonic level sensors as secondary elements. Alarms were integrated into the instrumentation system. These costs should be considered to be order-of-magnitude estimates only.

On the basis of these assumptions, the costs to implement flow metering on bypass flows at these 12 facilities is approximately $224,000 or $18,700 per plant on average. If it is assumed that these 12 facilities are representative of the other STPs in Ontario and that costs are not a function of plant size, the total cost for providing this level of monitoring in all Ontario STPs excluding lagoons (243 facilities) is estimated to be $4.5 million. Confirmation of these cost estimates requires that significantly more data regarding typical quantities and frequencies of raw sewage bypassing at Ontario STPs be collected.

Based on discussions with plant operating staff and administrators during the site visits, there was some confusion regarding the need to report raw sewage bypass events to the MOE Spills Action Centre under the Spills Bill (Part IX of the Environmental Protection Act). Clarification of the requirements under the Act would be beneficial.

3.5.2 Nitrification Requirements

Indirectly, the MISA programme may also result in requirements for municipal STPs to achieve a partially nitrified effluent in order to comply with "whole effluent" toxicity limits. The cost impacts of this requirement on the 12 STPs included in this phase of the investigation were assessed. Two possible effluent limits were considered in the analysis:

Limit A: 8 mg/L NH_3-N, or 10 mg/L TKN if NH_3-N data were not available

Limit B: 3 mg/L NH_3-N, or 5 mg/L TKN if NH_3-N data were not available

TABLE 17

EFFECTS OF BYPASS RESTRICTIONS ON STP PERFORMANCE

Plant	Likely Performance Effects		Options Available to Reduce Effects
	Yes	No	
Plant A		✓	N/A
Plant B	✓		Peak Flow Storage Polymer Addition Collection System Rehabilitation
Plant C	✓		Peak Flow Storage Separate Peak Flow Treatment Collection System Rehabilitation
Plant D		✓	N/A
Plant E		✓	N/A
Plant F	✓		Peak Flow Storage Polymer Addition Step-Feeding Collection System Rehabilitation
Plant G	✓		Peak Flow Storage Step-Feeding Collection System Rehabilitation
Plant H	✓		Peak Flow Storage Polymer Addition Collection System Rehabilitation
Plant I		✓	N/A
Plant J	✓		Peak Flow Storage Polymer Addition Step-Feeding Primary Bypassing Collection System Rehabilitation
Plant K		✓	N/A
Plant L		✓	N/A

N/A = Not Applicable

Table 18 compares the effluent nitrogen (NH_3-N and/or TKN) concentration data from these 12 STPs for the five year period from 1986 to 1990 to the higher nitrogen limits (Limit A) on a monthly basis. The percentage of the time in each year that the limits were achieved is presented. In some cases, effluent nitrogen data are sparse. Nitrate and nitrite data, needed to confirm the occurrence of nitrification, are generally lacking. Table 18 also compares the estimated oxygen transfer capacity at each facility with the oxygen demand associated with carbon oxidation and complete nitrification. The average estimated solids retention time (SRT) is also presented. Based on these key parameters which influence nitrification, the probable cause of a lack of consistent nitrification is proposed for plants that did not meet the nitrogen limits.

A similar analysis with respect to the lower nitrogen limits is provided in Table 19.

Table 20 summarizes the results of these analyses. Six of the 12 STPs achieved the effluent nitrogen concentration targets of limit A (Plants A, E, G, I, K, L) on a relatively consistent basis over a five-year period, based on the available data. In addition, Plant D achieved the limit consistently in 1989 and 1990 after high concentration industrial discharges were brought under control. When Plant I did not achieve the TKN target concentration, it was attributable to high TSS concentrations in the effluent rather than a lack of nitrification. At these plants, no upgrading would be necessary to achieve level A nitrogen targets. Of the plants not achieving these limits, Plant J consistently met the nitrogen limits in the summer months but did not achieve the same degree of nitrification in the colder winter months. In this case, increasing the SRT in the winter should produce the required degree of nitrogen control. At two facilities (Plants B and H), insufficient oxygen transfer capacity was available to achieve nitrification. However, at both plants, standby blowers were available but not operated during periods of higher oxygen demand. Bringing these units on-line as needed should result in the required degree of nitrification. Two facilities (the high-rate Plant C and Plant F) would require significant capital works to achieve limit A. In the case of Plant F only aeration tankage (including oxygen transfer equipment) would be required. At Plant C, both aeration and clarification would be needed.

Capital costs to implement the upgrades needed at these facilities to achieve the 8 mg/L NH_3-N and/or 10 mg/L TKN limit were estimated. These should be considered "order-of-magnitude" estimates as they are based on vendor-supplied equipment costs and typical installation factors. Costs at a particular site will depend on actual labour and material costs, market conditions, final project scope, location, schedule and other factors. The estimated capital cost to achieve the nitrogen limits suggested in limit A for all 12 STPs is \$1,700,000, or about \$22 per m^3/d of design capacity. If it is assumed that the costs for upgrading these facilities to achieve this level of nitrogen control are representative of the costs which would be incurred at all secondary treatment plants in Ontario on \$ per m^3/d of design capacity basis, then extrapolating this result suggests an order-of-magnitude cost of \$100 million to achieve this limit province-wide.

Only two of the 12 STPs (Plants E and I) were able to achieve the more stringent effluent nitrogen limits proposed under limit B. Two plants (Plants J and L) should be capable of achieving the proposed limit by increasing SRT, particularly under cold

TABLE 18

COMPARISON OF STP PERFORMANCE TO HIGHER NITROGEN LIMIT (LIMIT A)

	PERCENT OF TIME LIMIT ACHIEVED										Estimated Oxygen Capacity (kg O_2/d)	Avg. Oxygen Demand (kg O_2/d)	Avg. SRT (d)	Probable Reason for Lack of Nitrification
	1986		1987		1988		1989		1990					
	NH_3	TKN	NH_3	TKN	NH_3	TKN	NH_3	TKN	NH_3	TKN				
PLANT A	100	100	100	100	100	100	100	100	100	92	1025-5550	5830	4.6	N/A
PLANT B	67	67	0	18	25	27	42	50	50	50	1 blower: 110-180 2 blowers: 220-360	304	43.6	D.O. deficiency
PLANT C	ND	42	ND	58	ND	30	ND	0	33	0	1 blower: 452 2 blowers: 904 3 blowers:1356	256	3.2	High rate plant High Load Low SRT
PLANT D	83	75	83	83	58	58	100	92	100	100	1 rotor: 270 2 rotors: 540	597	29.1	Industrial organic load
PLANT E	100	100	100	100	92	100	100	100	100	100	1 tank: 1620 2 tanks: 3240	Tank 1: 873 Tank 2: 963	Tank 1: 96.0 Tank 2: 88.3	N/A
PLANT F	ND	71	ND	40	ND	88	ND	40	ND	91	180-290	206	N.A.	Biological treatment limitation
PLANT G	100	88	100	88	100	63	100	50	100	50	650	800	N.A.	Nitrifies year-round
PLANT H	ND	44	63	11	67	63	78	38	100	78	1 blower: 160-200 2 blowers: 320-400 3 blowers: 480-600	250	37.8	D.O. deficiency
PLANT I	ND	67	ND	83	ND	100	ND	91	ND	100	N.A	N.A.	45.6	High effluent TSS
PLANT J	100	92	82	83	75	64	50	50	80	91	3570	2500	12.8	Low SRT
PLANT K	ND	75	ND	100	ND	100	ND	100	ND	100	180	162	41	N/A
PLANT L	92	92	100	100	90	90	92	92	100	100	5907	3563	2.9	N/A

N.A. = Not Available
N/A = Not Applicable
ND = No Data

TABLE 19

COMPARISON OF STP PERFORMANCE TO LOWER NITROGEN LIMIT (LIMIT B)

	LIMIT B ACHIEVED (% of time) NH_3 = 3 mg/L TKN = 5 mg/L										Estimated Oxygen Capacity (kg O_2/d)	Avg. Oxygen Demand (kg O_2/d)	Avg. SRT (d)	Probable Reason for Lack of Nitrification
	1986		1987		1988		1989		1990					
	NH_3	TKN	NH_3	TKN	NH_3	TKN	NH_3	TKN	NH_3	TKN				
PLANT A	64	73	83	83	92	83	100	100	100	92	1025-5550	5830	4.6	Low SRT Possible aeration deficiency
PLANT B	42	42	0	9	8	9	33	50	25	33	1 blower: 110-180 2 blowers: 220-360	304	43.6	D.O. deficiency
PLANT C	ND	8	ND	16	ND	0	ND	0	0	0	1 blower: 452 2 blowers: 904 3 blowers:1356	256	3.2	High rate plant High load Low SRT
PLANT D	33	75	83	83	42	33	80	75	92	90	1 rotor: 270 2 rotors: 540	597	29.1	Industrial organic load D.O. deficit
PLANT E	100	100	100	92	72	75	100	92	100	75	1 tank: 1620 2 tanks: 3240	Tank 1: 873 Tank 2: 963	Tank 1: 96.0 Tank 2: 88.3	N/A
PLANT F	ND	43	ND	30	ND	63	ND	0	ND	82	180-290	206	N.A.	Biological treatment limitation
PLANT G	100	88	100	50	88	25	100	13	88	38	650	800	N.A.	D.O. deficiency
PLANT H	ND	33	63	0	0	63	33	25	25	50	1 blower: 160-200 2 blowers: 320-400 3 blowers: 480-600	250	37.8	D.O. deficiency
PLANT I	ND	50	ND	75	ND	100	ND	82	ND	100	N.A	N.A.	45.6	High effluent TSS
PLANT J	92	92	55	58	58	55	42	42	60	73	3570	2500	12.8	Low SRT
PLANT K	ND	63	ND	25	ND	100	ND	92	ND	50	180	162	41	D.O. deficiency
PLANT L	92	75	100	100	90	70	83	67	92	92	5907	3563	2.9	Low SRT

N.A. = Not Available

N/A = Not Applicable

ND = No Data

TABLE 20

UPGRADING REQUIRED TO ACHIEVE NITRIFICATION LIMITS

Plants Currently Achieving Limits	
Limit A	Limit B
Plant A Plant E Plant D (1989/90) Plant G Plant I Plant K Plant L	Plant E Plant I

Upgrading Needed to Achieve Limit A				Upgrading Needed to Achieve Limit B			
Increase SRT	Increase O_2 Transfer	Increase Aeration Tankage	Increase Clarification	Increase SRT	Increase O_2 Transfer	Increase Aeration Tankage	Increase Clarification
Plant J	Plant B Plant H	Plant C Plant F	Plant C	Plant A Plant J Plant L	Plant A Plant B Plant D Plant G Plant H Plant K	Plant C Plant F	Plant A Plant C

weather conditions. Plants B, H and K should be capable of achieving the desired level of nitrification by utilizing standby blower capacity under peak loading conditions to satisfy the maximum oxygen demand. At these five facilities, the nitrogen concentrations of limit B should be achievable with minimal capital cost. The other five STPs would require larger capital expenditures to achieve the desired level of nitrification. This would involve increased oxygen transfer capacity (Plants A, D and G), increased aeration tankage and oxygen transfer (Plants C and F) and/or increased clarification to handle higher solids loading rates anticipated at higher SRTs (Plants A and C).

The estimated capital cost to achieve the nitrogen limits suggested in limit B for all 12 STPs is \$14,300,000 or \$185 per m^3/d of design capacity. If it is assumed that the costs for upgrading these facilities to achieve this level of nitrogen control are representative of the costs which would be incurred at all secondary treatment plants in Ontario on a \$ per m^3/d of design capacity basis, then extrapolating this result suggests an order-of-magnitude cost of \$860 million to achieve this limit province-wide.

Achieving partial nitrification (8 mg/L NH_3-N and/or 10 mg/L TKN) can have implications on a plant's ability to comply with effluent total BOD_5 limits. The nitrogenous oxygen demand associated with the oxidation of residual ammonia in the effluent sample can significantly increase the result of the BOD_5 test if nitrification inhibitor is not used. The performance data from Plant J reflect the effect of partial nitrification on the ability of a facility to comply with effluent total BOD_5 limits.

4.0 APPROACHES TO IMPROVE PERFORMANCE

4.1 GENERAL

Historically, poor performance at municipal STPs has been addressed by one of two methods. If the facility is near its nominal design capacity either organically or hydraulically, a program of plant expansion is normally initiated. This capital works program may also address design deficiencies identified within the existing facility. If the facility is underloaded, physical modifications to address specific design problems identified as a result of process studies are often implemented to upgrade the performance of the plant. These traditional approaches have not always resulted in a cost effective solution to plant performance problems.

In the first case, the expanded plant may show improved performance because of the larger safety margin available in the facility; however, as plant loading increases, other non-design related factors which impaired the performance of the original facility may resurface with the result that poor performance again becomes apparent. This is evidenced from the fact that a large number of non-complying plants operate at below their design capacity. This plant expansion approach does not result in effective use of existing facilities or capital dollars because the basic problems which led to poor performance were not addressed by the plant expansion.

In the second case, the physical modifications may address some of the factors which contributed to the poor plant performance. However, this investigation as well as similar work in the U.S.(2,3,4,6,7) showed that, at each plant, there is a unique combination of several factors which all contribute to poor plant performance. Many of these factors are not design related. Since physical modifications only address design factors, other operational, maintenance or administrative factors will continue to impair plant performance despite the physical improvements made at the plant.

In order to address all of the factors which contribute to poor performance at a specific plant, it is necessary to conduct a correction program designed specifically for that plant. Some components of the program may be sufficiently generic to be applicable to all plants. Other components may need to be tailored for a particular problem unique to that plant. In the following subsections, generic approaches to address some of the most commonly encountered problem areas in the Ontario STPs reviewed in Phase 1 of this project are discussed. These approaches are not intended to be applicable to only the 12 STPs visited and the seven STPs for which process study reports were reviewed. More STPs suffer from performance problems than the available data suggests. Because of the methods used for performance sample collection and the amount of effluent quality data available for some plants, the available information may not accurately reflect the actual performance of many plants. For example, historic data for Plant F indicates that in 1990 an average effluent quality of 4.7 mg/L BOD_5 and 6.5 mg/L TSS was achieved despite the fact that sludge was only hauled from this plant once during the year and substantial quantities of raw sewage bypassed treatment during wet weather periods. All plants would benefit to some extent from programs, initiatives or policies aimed at addressing the most commonly encountered factors contributing to poor performance at the STPs analyzed during this investigation.

4.2 SLUDGE MANAGEMENT LIMITATIONS

Inadequate sludge wastage and disposal from the STP was the most important factor affecting the performance of all of the facilities evaluated in this investigation. In some cases, the lack of control of the sludge inventory in the plant which resulted was caused by the lack of appreciation on the part of plant staff regarding the importance of sludge inventory control to the performance of the biological processes. This was evident from the lack of records at some facilities regarding amounts of sludge wasted or hauled from their plants. Improving the ability of plant staff to understand the importance of sludge wastage control and to make effective process control decisions is addressed separately in Section 4.3.

In a significant number of cases, there was insufficient storage available for waste sludge (at five plants inadequate sludge storage capacity was noted as a contributor to poor performance). Although some plants had arranged for additional sludge storage to augment that provided in the original plant design, others were attempting to operate an agricultural sludge utilization program with less than a month of sludge storage capacity. Two plants, that disposed of sludges to agricultural land, had no land approved to receive sludge at the time of the site visit. There was a general lack of coordination of agricultural sludge disposal programs. Few plants had contingency plans to address problems with sludge unsuitable for land application or prolonged periods of inclement weather which would restrict access to disposal land. Some of the larger plants had significant bottlenecks in sludge treatment process units. Inadequate sludge disposal capacity was the seventh most important factor at the generally larger plants where process studies were done. As a direct result of inadequate sludge storage, treatment or disposal capacity, the operator is forced to abandon sludge wastage because of physical limitations in his plant and is no longer able to control his biological treatment process. The result is the inevitable loss of solids to the plant effluent.

Adequate sludge storage must be available outside of the liquid treatment train to support the ultimate sludge disposal program. In the case of smaller treatment facilities, this is typically land utilization. Four to six months of storage may be needed to support a land utilization program in Ontario (40). In plants with a history of heavy metal contamination, a contingency disposal alternate should be identified and approved in the event that the land utilization program must be abandoned due to the metal content of the sludges. More than the minimum amount of land required to support the disposal program must be available and approved at any time to account for crop rotation or other conditions which might prevent a site from being available for disposal. Sufficient lead time must be provided to ensure that all necessary approvals can be completed before the land is needed for disposal of sludge. At the same time, more expedient approval of land for sludge application would also help reduce instances where plants have inadequate approved land available for sludge disposal.

In many cases, sludge utilization on agricultural land is viewed as a low cost, low effort means of sludge disposal. However, an effective sludge utilization program requires good management to coordinate the approvals process, to ensure that adequate storage is available and that the farmers' needs are adequately addressed. In many cases, there would be benefits to a more regionalized approach to the sludge utilization program in which a number of small STPs in the same geographical area shared a common storage facility and disposal coordinator. This approach would reduce the cost of providing storage at each individual plant, would allow a more coordinated approvals process and would result in reduced cost due to larger haulage contracts. Issues of liabilities associated with sludges received from different municipalities and cost sharing would need to be addressed.

In summary, the following steps are suggested to address sludge wastage and disposal limitations in Ontario STPs:

- Adequate storage capacity should be available to support the ultimate disposal method used at each individual STP. In the case of land application programs, up to six months storage capacity may be required.
- Contingency plans should be in place which identify an approved alternate disposal method in the event that sludges are not suitable for land disposal or inclement weather prevents access to disposal sites for a period beyond the capacity of the available storage.
- Sufficient approved land should be available at any time to support the requirements of the land utilization program at each STP. This land requirement is greater than the minimum land requirement since some land may not be available because of crop rotation or other factors.
- More expedient approval of land for sludge application would help to reduce the number of cases where inadequate land is available to support the sludge disposal program.
- Regionalization of a number of small STPs into a common sludge utilization program should be considered.
- Improved record-keeping and reporting of the volumes and masses of sludges wasted from the liquid treatment system and disposed of from the plant should be required so that a solids balance can be conducted on the plant to determine the adequacy of the sludge wasting program.

4.3 OPERATOR TRAINING

A general lack of understanding of the fundamentals of sewage treatment processes and the inadequate application of these concepts to control of the specific facility was the second most important factor contributing to poor plant performance. This was demonstrated in a number of different ways at different plants. At some facilities, there was a total lack of process monitoring in the plant (the seventh most important factor in all plants investigated) on which to base any process control decision. At other plants, there was no evidence that sludge was wasted on a routine basis to control the solids inventory in the biological system. This lack of understanding generally resulted in poor performance from a plant which was adequately designed to handle the loading that it received. At the opposite extreme, operators with a good understanding of operation of wastewater treatment processes were able, in some cases, to overcome design deficiencies by modifying operating conditions.

Lack of formal training in sewage treatment plant operation was not identified as a problem area. Operators generally were "qualified" to operate their facilities based on training courses attended. With a few exceptions, adequate staff were available to conduct the level of testing needed to ensure adequate plant performance, but emphasis was placed on maintenance tasks rather than process control tasks. The need to keep equipment operational tended to overshadow the need to operate the process under controlled conditions, particularly at smaller facilities.

The lack of appreciation on the part of trained operators of the need to control the process and the lack of ability of some operators to apply the knowledge gained from the training material to their facility suggests that the current methods of training need to be reviewed. More emphasis needs to be placed on hands-on training, delivered to the operating staff at the facility which they are responsible for operating. This approach would ensure that the concepts are demonstrated with the process configuration and equipment which the operator must use to control his particular plant.

Lack of adequate O&M manuals and other sources of technical support also restricts the ability of plant operators to apply fundamental principals of plant operation to their facilities. This represented the sixth most common factor and the tenth most important overall (Table 14) and is related to operator training. Few plants had O&M manuals and those that did generally contained suppliers' information on equipment maintenance. These manuals reinforce the emphasis on maintenance over process control. Technically correct operating manuals emphasizing the application of wastewater treatment process control concepts in the context of the actual facility being operated allow the principles learned in training courses to be directly applied. Operating staff must have a role in developing the operating manuals so that the manual is understandable to them and is responsive to their needs.

At several plants visited, difficult process problems such as filamentous bulking sludges or partial nitrification contributed to poor plant performance. Operators of these facilities generally had no access to technical specialists who could provide support or direction to assist in troubleshooting these problems. Some means of encouraging the use of technical process specialists by municipal plant operators should be considered, including the implementation of programs which would provide plant operators with advice from these specialists where conditions warrant. This assistance could be provided through an operator association such as the Professional Wastewater Operator Division (PWOD) of the Pollution Control Association of Ontario (PCAO).

In summary, the following steps are suggested to address the operator training related factors noted during this investigation:

- Current methods of delivering training to operating staff need to be reviewed and consideration given to training staff at the facilities which they are responsible for operating.

- O&M manuals emphasizing process control actions specific to the facility should be prepared for all STPs.
- Programs should be developed which would give municipal treatment plant operators access to technical process specialists to solve process problems and improve plant performance.

4.4 ADMINISTRATIVE SUPPORT

While the lack of understanding and application of process control concepts was an important factor contributing to poor performance, the ability of the operator to effectively operate the facility was often restricted by the policies of and the support provided by the administration responsible for the facility. These two factors were nearly equal in terms of the frequency at which they were observed and the importance of their contribution to the performance problems.

Generally, the sewage treatment facility is the least visible component of the infrastructure for which the municipality is responsible. Hence, it generally receives a lower priority in terms of financial and other support than more visible elements such as roads, water supply and solid waste disposal. The public seldom is concerned about the operation of the STP unless there are obvious odour problems or visible pollution problems in the receiving stream. The emphasis is often placed on controlling the costs of the plant operation rather than on improving performance. There is little incentive through regulatory enforcement programs for municipalities to optimize the performance of the STP, and, in most cases, little disincentive to continue to operate in a non-complying mode.

Many administrators do not have sufficient technical knowledge of wastewater treatment to understand the complexities of the operation or the possible implications of their policies on plant performance. Thus, there is often insufficient attention paid to controlling industrial discharges (the ninth most important factor) or extraneous flows (the sixth most important factor). This problem can be compounded in situations where the municipality has jurisdiction over the collection system and the province operates the treatment facility.

Increased enforcement of effluent quality limits through the issuance of Certificates of Approval with specific effluent concentration and monitoring requirements will raise the awareness of plant administrators regarding the need to ensure that plant performance is maintained. It will also provide an incentive to administrators to improve performance and address factors such as industrial discharges and extraneous flow which contribute to poor performance. This must however be tempered with a means of controlling unnecessary and expensive plant expansion as the principle means of achieving compliance with permit requirements. As has been noted, capital intensive plant expansion is not a guarantee of improved plant performance. All factors contributing to poor performance at a facility must be addressed before optimum performance can be assured. This can only be achieved by a thorough review of the facility by technical process specialists before an expansion is approved. The approaches used by regulatory agencies in U.S. states such as Wisconsin and New York should be thoroughly reviewed and considered during the development of enforcement and assistance programs for application in Ontario. These programs are described in Appendix 1 and 2 of this report.

4.5 HYDRAULIC LOADING

Excessive hydraulic loading was the fourth most important factor in all of the plants visited and was often directly related to extraneous flows into the collection system, the seventh most common problem encountered. As noted in Section 3.2.1, eight of the 12 plants visited were operated at more than 90 percent of hydraulic capacity based on the five year average flow. However, only two plants had organic loads in excessive of 90 percent of their design capacity. This suggests that significant dilution of raw wastewater strength occurs due to infiltration and/or inflow into the collection system. Six facilities experienced average day per capita flows in excess of 600 L/d with no major industrial inputs to justify the high wastewater generation rate.

Extraneous flows usually cause short term performance problems under wet weather conditions. Only in exceptional cases is the problem so serious as to constitute a major performance limiting factor on a continuous basis, although even short-term excess flows can cause non-compliance with monthly or daily effluent limits. The Ministry of the Environment under the Lifelines Program currently provides financial support to municipalities to undertake Sewage Collection System Needs Studies aimed at identifying sources of extraneous flow and developing remediation plans where appropriate. Efforts in this area must be continued since it is apparent that many of the small municipalities visited during this study were using a significant amount of their available treatment capacity to treat clean water entering the collection system via sump pumps, roof leaders and other sources. There needs to be more consideration given to the relative costs and benefits of sewer rehabilitation compared to the costs of providing sewage treatment plant capacity to handle the extraneous flows. Currently, NEEDS Studies and Class Environmental Assessments prior to plant expansion are not integrated so as to produce a comprehensive overall plan for collection and treatment of domestic wastewater.

High hydraulic loading normally affected the performance of the secondary clarifiers more than other process units in the liquid treatment system. Although adequate biological treatment capacity, in terms of aeration basin HRT and oxygen transfer capacity may be available when the plant reaches its "hydraulic" capacity, few plant expansions consider adding only additional clarifier capacity. In many situations, this may be a cost effective alternative. There are also means available to improve the performance of existing clarifiers to achieve adequate performance at higher surface overflow rates. Since the degree of success is strongly dependent on the design and operation of the specific clarifier, these procedures should be assessed at the particular plant before a decision to increase capacity is made. Alternatives include:

- The addition of baffles to the clarifier to prevent short-circuiting and improve utilization of the entire clarifier surface for settling. This procedure was shown to be successful to improve the performance of rectangular clarifiers at the Corbett Creek WPCP (18) and circular clarifiers at the Windsor Little River WPCP (42).

- Use of polymers to enhance settling characteristics of sludges at peak flow conditions. This was successfully demonstrated at the Duffin Creek WPCP (19). In this case, polymers are added to the inflow to the clarifiers only when the raw sewage flow exceeds a predefined maximum.

- Utilization of step-feed capabilities to reduce the solids loading on the clarifiers during periods of peak flow. This approach has been successfully demonstrated at the Dundas WPCP (43), the Hamilton Woodward Avenue WPCP (44) and at numerous facilities in the U.S. including plants in New York and Houston.

- Adjustment of return sludge rates in response to changes in sludge blanket depth measurements made by plant staff.

- Modifications to the location and configuration of weirs and launders to prevent short-circuiting (4).

- Flow equalization or peak flow storage in the collection system.

The best approach at a specific plant will depend on the flow profile, the aeration tank configuration, the sludge settling characteristics, and the clarifier design.

High extraneous flows usually occur in the wet spring months, the same time period when sludge disposal may be curtailed because of soil conditions. In plants where the liquid treatment units are used for excess sludge storage, very high MLSS concentrations are often maintained in the aeration basins under these circumstances. The high solids inventories and high sludge blankets in the clarifiers lead to solids washout from the clarifiers under peak flow conditions. Operating staff often confuse this sludge washout with sludge bulking. The actual problem relates to the high solids loading on the clarifier which can occur and subsequent thickening failure of the clarifier. Several of the plants visited operated at conservative surface overflow rates even at peak flow conditions, but peak solids loading rates were in excess of 300 $kg/m^2.d$. These solids loadings typically resulted in the loss of solids to the plant effluent.

Five of the plants visited suffered from hydraulic loading problems due to the design of the raw sewage pumping station. Raw sewage lift pumps operating in an on/off mode with capacity of several times the average daily flow capacity of the plant will produce significant flow surges through the entire plant. The impact will be most noticeable in the secondary clarifier where the sludge blankets can be washed out every time the lift pumps are activated. The effects of raw sewage lift pump operation on effluent TSS concentrations was demonstrated during the process studies conducted at the Hespeler WPCP (16). Effluent TSS concentrations increased to more than 30 mg/L in response to peak flow cycles from the sewage lift stations. Replacement of lift pumps with capacities better matched to the plant capacity or with variable capacity pumps will address this problem. Alternately, upstream process units such as the aeration basin may be used to protect the clarifier from flow surges by storing peak flows when the lift stations are operational. The amount of storage available will depend on the type of aeration hardware in place, (mechanical surface aerators are sensitive to the degree of submergence) and on the plant hydraulic profile.

4.6 INDUSTRIAL LOADING

Although the effects of industrial discharges, in this study, were considered solely from the standpoint of their impact on the ability of the plant to perform in terms of BOD_5 and TSS objectives, industrial loading was the tenth most common factor and the ninth most important factor affecting plant performance. In the majority of cases, industrial discharges produced organic loads beyond the capacity of the biological system. The two plants which were operating at organic loading beyond their capacity (Plant D and Plant L) both received significant amounts of BOD_5 loading from industrial sources. In few cases were toxic effects of industrial discharges noted.

The Ministry of the Environment is currently implementing a Sewer Use Control Program as part of the MISA programme (45). When this program is in place, stricter controls will be placed on the discharges of industry to the sanitary sewer, alleviating some of the industrial discharge problems. Considerable emphasis in the sewer use program has been placed on control of toxic pollutants which may pass through the treatment plant, interfere with treatment plant operation, contaminate sludge or represent a hazard to the health of the sewage treatment plant operator. It is important that the sewer use program also address conventional contaminants such as BOD_5 and TSS. The discharge of these contaminants can have significant impact on the performance of the treatment facility if it is not designed to handle the increased and potentially variable loading from industrial sources.

It was noted that few municipalities had wastewater flow or characterization data from industries discharging to their facilities, even in cases where industrial loading was felt to be a problem. The MISA programme will require more comprehensive monitoring of these wastewaters.

In the past, administrators have allowed high strength discharges to the wastewater treatment plant from industrial sources as a means of attracting and retaining industry or have charged a surcharge for overstrength wastewater to recoup some of the costs of treatment. These policies do not always consider the potential impacts of these discharges on the performance of the STP, leaving the plant operator with a facility that cannot meet its effluent objectives.

4.7 OXYGEN TRANSFER

Inadequate oxygen transfer was not a factor commonly identified or found to be an important contributor to poor plant performance at the 12 plants visited; however, it was noted at several of the STPs where process studies were done. Overall, it was the eighth most important factor contributing to poor performance. As noted, the difference in degree of importance accorded this factor may relate to the emphasis placed on oxygen transfer measurements during the process studies. In most of the smaller plants visited, measurements of dissolved oxygen concentrations in aeration basins were taken very infrequently. More detailed analysis of the oxygen transfer capacity at the sites visited might identify that it is more important than currently thought. Analysis based on typical oxygen transfer efficiencies for the aeration hardware at the 12 plants visited indicated that all except Plants A, D and G had adequate oxygen transfer capacity to meet both the carbonaceous and nitrogenous demand on the plant under average loading conditions.

Increases in oxygen transfer capacity can often be accomplished by relatively low capital cost upgrading if the aeration tankage is adequate to provide treatment in terms of the HRT, F/M and SRT. At four of the seven STPs where process studies were undertaken, upgrading of oxygen transfer equipment was recommended. At the Belleville WPCP, it was recommended that fine bubble diffusers be installed in the existing aeration basins to replace the existing coarse bubble system and double the transfer capacity (15). A similar recommendation was made as a result of studies done at Burlington Skyway WPCP (20). At the Highland Creek WPCP, fine bubble diffused aeration is being added to part of the secondary plant which currently uses mechanical surface aerators (46). At the Corbett Creek WPCP (18), submerged jet aeration equipment was added to the mechanically aerated basins to rectify deficiencies with the operation of the two-speed system. Upgrading which was underway at Plants A and G include retrofitting of fine bubble aeration to replace existing coarse bubble systems.

At smaller treatment plants where a common air supply services the aeration basin, air lift pumps, grit removal facilities and aerated sludge holding tanks, it is usually impossible to measure the air supply available for the aeration basin. In such cases, separating the air supply to the aeration basin and providing air flow measurement instrumentation will allow the operator to adjust air flow rates independent of the other uses of the air supply. This approach was used at the Hespeler WPCP (16), along with addition of variable speed control on the blowers, to provide positive control of air supply to the aeration basin.

Few plant operators attempted to utilize the minimal amount of control of oxygen transfer available to them. Since DO concentrations were seldom measured, many operators did not recognize the need to increase or decrease oxygen transfer. In mechanically aerated plants, some adjustment of liquid level was often available to modify the transfer efficiency of submergence sensitive aeration hardware. In plants with diffused air supplies, additional blowers were often available but seldom used. In addition, coarse adjustments to the air flow to various parts of the plant could be done to increase or decrease the air supply to the aeration system. More frequent monitoring of DO concentration is needed, along with more design flexibility to control the oxygen transfer hardware.

4.8 INSTRUMENTATION AND CONTROL

Inadequate I&C equipment was identified as a factor at all plants, although it was never the most important factor. Generally, the lack of I&C hindered the ability of the plant operator to make key process measurements and decisions. The most serious limitation was the lack of instrumentation to measure return sludge and waste sludge flowrates. This was particularly true in the small package plants where air lift systems were used to accomplish sludge return and sludge wastage, although problems were also apparent in facilities with mechanical return systems. Without this instrumentation, it is very difficult to adjust return rates to accommodate changes in flow or settling characteristics or to control the solids inventory in the plant. Other noticeable deficiencies included lack of dissolved oxygen measurement equipment in plants where oxygen transfer problems were apparent, inaccurate raw sewage or final effluent flow sensors, lack of plant bypass flow monitoring and lack of instrumentation to measure critical flow splits within the plant.

In most cases, inexpensive modifications to the system could be made to allow the addition of RAS or WAS flow metering capability even at plants where air lifts are used for these services. At the Corbett Creek WPCP, recommendations were made to improve raw sewage and in-plant flow split metering (18). On-line dissolved oxygen sensors should be considered in plants where there are wide variations in loading to the aeration basin.

Adequate instrumentation eases the task of the operator in monitoring and controlling his plant. Agencies like the Instrumentation Testing Association (ITA) currently evaluate instrumentation for use in wastewater treatment plants and have data bases available which provide summaries of user experience. As a result of the activities of agencies like ITA, the performance of on-line instruments has improved significantly and dependable equipment is available to the plant operator.

In many plants, there is little flexibility in operating mode available to the operator to address adverse process conditions. Flexibility, along with process instrumentation, are often features of STPs which are removed during plant design as cost saving measures. Often, the removal of these features from the design seriously restricts the ability of the operator to optimize the performance of the facility. Since the costs of I&C typically represent less than 5 percent of the total cost of a facility (47), limiting the ability of plant staff to make key process measurements in order to reduce costs may represent false economy. Care must be taken to ensure that "value engineering" decisions do not impact on the operability of the treatment plant. Operating staff should be included throughout the design process to ensure that operational input is included in design decisions.

4.9 EFFECTS OF STP OPTIMIZATION

The design and operation of the 12 plants visited were assessed to determine those at which improvements in performance could be achieved without major capital expenditure for plant expansion. This assessment is based on the current loading to the plant. Some of these plants had already taken steps to improve performance and the performance improvement is apparent in the available effluent quality data (refer to Appendix A) after the modifications were made. At other plants, capital expansion has already been initiated because growth requirements in the serviced area will result in wastewater flows exceeding the nominal capacity of the existing facility. This analysis is not intended to suggest that these expansions are not necessary since the ability to maintain performance at the future flow and loading has not been considered in this analysis. The analysis is also based on the current flow which is treated through the plant. At some of the plants visited, substantial quantities of wastewater were bypassed upstream of the plant under wet weather flow conditions. In most cases, the amount of flow bypassing the plant was unknown. Hence, the impact on plant performance of treating this additional flow cannot be accurately estimated. More discussions regarding the implications of more restrictive control on bypassing was included in Section 3.5.1.

Based on the available information on the 12 plants visited, it is estimated that performance improvements could be achieved at ten of the facilities through modifications to operating strategies and minor physical changes. In the majority of cases, these improvements will only be achieved through upgrading of the ability of the plant operators to implement proper process control actions. At ten of the facilities, the most important operational change required is the implementation of an effective sludge wastage program to achieve effective biomass inventory control. Achieving this will require that the operators recognize the importance of effective biomass control for optimum plant performance. More comprehensive monitoring to support process control is recommended at six facilities. Additional sludge storage capacity to eliminate the use of the liquid treatment train for sludge storage is needed at seven plants to allow the operating staff to effectively control their sludge inventory. O&M manuals stressing process control actions rather than equipment maintenance would help operating staff at virtually all plants, but are particularly important at eight of the 12 facilities visited.

In terms of physical modifications other than the addition of more sludge storage capacity, the most commonly recommended changes included:

- modifications to influent pumping stations to reduce peak flows resulting from the on/off operation of the raw sewage lift pumps, suggested at five plants.
- addition of improved or upgraded instrumentation, at all plants.
- improve clarifier hydraulics by baffling or other procedures, at two plants.
- addition of standby sludge pumping capacity, at two plants.

All of these changes constitute low capital cost modifications.

At several facilities, increased support from administration is needed in conjunction with these physical and operational changes to ensure continued effective performance. This support includes continued extraneous flow reduction in the collection system (six facilities) and improved control of industrial discharges (three facilities).

At the ten facilities where it is expected that performance improvements could be achieved without major capital expenditure, the estimated reduction in the loading of BOD_5 and TSS was calculated. These calculations are based on the best available estimate of the effluent quality for the year in which the performance at each plant was the worst. These effluent data may underestimate the actual loading because of sampling procedures and frequencies, and do not include any loading from bypassed flow not passed through the plant. It is assumed that the modifications suggested will upgrade the performance to the plants to meet the monthly effluent quality objectives stated in Section 2.2 (extended aeration plants - 15 mg/L BOD_5 and 20 mg/L TSS; conventional and high-rate activated sludge plants - 25 mg/L BOD_5 and 25 mg/L TSS). Obviously, confirmation of the effluent quality improvement achievable would require implementation of the recommendations at each of the facilities investigated and follow-up monitoring.

Based on this analysis, it is estimated that the load reduction achievable from the ten plants where significant capital investment is not necessary would be approximately 102 tonnes per year of BOD_5 and 216 tonnes per year of TSS. This represents a reduction of about 27 percent reduction in BOD_5 and 30 percent in TSS from these ten facilities compared to the actual discharges for the year being considered.

At the two other facilities, more substantial capital investment would be needed before significant improvement in performance would be achieved. However, in both cases, the capital expenditures associated with the required upgrading are less than those which would be incurred in a plant expansion. At Plant A, modifications to the plant flow scheme to utilize the existing lagoons as equalization basins for peak wet weather flows and upgrading of oxygen transfer efficiency by retrofitting of fine bubble diffusers would be recommended in order to effectively handle the existing loading. At Plant C, the design and condition of the secondary clarifiers preclude effective operation of the plant. These process units would need to be replaced before optimum performance could be achieved. Other minor physical upgrading (improved instrumentation, modifications to influent pumping station) and operational changes (increased process monitoring, implementation of improved biomass inventory control, increased administrative emphasis on performance) would also be needed at one or the other of these two plants.

After these modifications were implemented at these two plants, the estimated reduction in effluent BOD_5 and TSS loading accomplished overall from the 12 plants would be 113 tonnes per year and 335 tonnes per year respectively. This represents a reduction of 30 percent in BOD_5 discharged and 46 percent in TSS discharged from these facilities compared to the actual discharges for the year considered.

4.10 COSTS OF STP OPTIMIZATION

Estimated costs were developed for implementing the suggested improvements at the 12 STPs visited. These costs **only** consider physical changes to the plant or operational modifications to improve plant performance. Costs were **not** developed for the implementation of policies or programs to upgrade operator process control skills through improved operator training practices, increased enforcement activities to provide an incentive to optimize performance or changes to administrative or policy factors currently limiting plant performance. **All of these factors must be addressed before long-term improvements can be made at these sewage treatment facilities.**

The estimated cost which would be incurred at these 12 STPs to undertake the suggested upgrading is \$4,700,000. A large fraction of this total (67 percent) would be incurred at the two plants where significant physical upgrading would be needed to improve performance (Plant A and Plant C). These upgrading costs are equivalent to approximately \$61 per m^3/d of design capacity at these 12 STPs. If it is assumed that similar costs would be incurred to optimize the performance of secondary STPs in Ontario that did not meet monthly average BOD_5 or TSS guidelines in 1988 (approximately 63 facilities or 34 percent of the total), then the order-of-magnitude costs associated with upgrading STPs province-wide through similar process optimization approaches are estimated at \$100 million.

5.0 CONCLUSIONS

The overall objective of this specific component of the investigation was to identify the principal factors limiting the performance of Ontario STPs and to recommend approaches to address these performance limiting factors. Twelve STPs with a history of performance problems related to poor BOD_5 and/or TSS removal were subjected to an extensive evaluation to identify the causes of poor performance. To support this analysis, the findings of detailed process studies conducted at seven other STPs were reviewed and integrated with the results of the assessments conducted at the 12 STPs. The major findings of this phase of the investigation are summarized in the subsections below.

5.1 FACTORS AFFECTING STP PERFORMANCE

It was found that there was a unique combination of design, operational and administrative factors which contributed to poor performance at any specific plant. Equipment maintenance was not a factor contributing to poor performance. In order to achieve long-term performance improvements, all of the factors which contribute to poor performance must be addressed. Factors which most significantly contributed to poor performance are discussed below.

- Inadequate sludge wastage and disposal from the STP was the most important factor affecting performance at the facilities evaluated in this investigation. In plants utilizing land application for final sludge disposal, several had less than a month of sludge storage capacity. Two such facilities had no land approved to receive sludge. There was a general lack of co-ordination of the disposal programs. Plants did not have contingency plans to deal with inclement weather or unacceptable sludge quality.

- A general lack of understanding of the fundamentals of sewage treatment processes and the inadequate application of these concepts to control of the facility was the second most important factor contributing to poor plant performance. At some plants, there was a total lack of process monitoring and testing on which to base process control decisions. At other plants, sludge was not wasted on a routine basis to control the solids inventory in the biological system. Poor or non-existent O&M manuals contributed to the problem. The lack of process monitoring and inadequacy of O&M manuals were also noted frequently as factors contributing to poor performance (seventh and tenth most important factors, respectively).

- The ability of the operating staff to effectively operate the STP was often restricted by the policies of and lack of support provided by the administration responsible for the facility. Administrators often do not have sufficient technical knowledge of wastewater treatment to understand the implications of their policies on plant performance. Thus, insufficient attention is paid to controlling industrial discharges or extraneous flows.

Regulatory enforcement activities do not provide incentive to optimize performance nor disincentive to continue to operate in a non-complying mode.

- Excessive hydraulic loading was the fourth most important factor limiting plant performance. Eight of the 12 plants visited were operating at more than 90 percent of hydraulic capacity. Performance at five of these STPs was further impaired by the on/off operation of over-sized raw sewage lift pumps which created large hydraulic disturbances in the plant.
- Inadequate instrumentation and control (I&C) equipment was identified as a factor limiting performance at all plants and ranked fifth overall in importance. The most serious limitation was the lack of instrumentation to measure return sludge and waste sludge flowrates. Other noticeable deficiencies included lack of dissolved oxygen measurement equipment in plants with oxygen transfer limitations, inaccurate raw sewage or final effluent flow sensors and lack of meters to measure bypass flows and internal flow splits within the plant.
- Extraneous flow (I/I) effects were the sixth most important factor identified. While eight of 12 plants were operating at more than 90 percent of hydraulic capacity, only two were operating at more than 90 percent of organic (BOD_5) load capacity. Six facilities have average day per capita flows in excess of 600 L/d with no major industrial inputs to justify the high wastewater generation rate.
- Oxygen transfer limitations ranked eight overall as a factor contributing to poor plant performance. This factor was more often observed at plants where oxygen transfer efficiency measurements were made than at plants where oxygen transfer capacity was calculated based on typical oxygen transfer efficiencies. Limited monitoring of aeration basin DO concentrations was done. Few operators utilized the minimal amount of control of oxygen transfer available in their facilities because the information needed to decide to increase or decrease oxygen transfer was not available.
- Industrial loading was the ninth most important factor affecting plant performance. Industries were generally responsible for producing excessive and variable organic (BOD_5) loads rather than toxic or inhibitory effects on the treatment processes. Few municipalities had industrial wastewater flow or characterization data even in cases where industrial loading was considered a problem.

The findings of this evaluation generally concur with those of similar investigations in the United States (2,3,4). In the U.S. studies, deficiencies in the application of operator knowledge of wastewater treatment and improper interpretation of the results of process testing were identified as the most significant problems affecting the performance of STPs. Other significant factors were extraneous flow, sludge wastage capability and availability of technical guidance to plant staff.

5.2 BENEFITS AND COSTS OF STP OPTIMIZATION

- Based on the available information on the 12 STPs visited, it was estimated that performance improvements could be achieved at ten of these facilities through modifications to operating strategies and minor physical changes to the facility. More costly physical modifications in addition to minor process and operational changes would be required at the other two STPs to improve performance. As a result of these changes, the overall reduction in BOD_5 and TSS effluent loading from these 12 plants would be about 30 percent and 46 percent, respectively. The total costs of the physical changes needed to achieve this effluent quality improvement was estimated at approximately $4,700,000. About 67 percent of this cost would be incurred at the two plants where significant physical upgrading was needed.

- Assuming that the optimization costs projected for these 12 STPs are representative on a $ per cubic metre of design capacity basis, the total costs of physical changes to optimize operation of mechanical secondary STPs province-wide is estimated at $100 million.

- These costs do not include any cost related to improving operator knowledge or addressing administrative factors which also impacted on plant performance. All of these factors must be addressed before long-term performance improvements can be accomplished.

5.3 EFFECTS OF LIMITING BYPASS AND REQUIRING NITRIFICATION ON STP COMPLIANCE

- Based on the limited data available, limiting raw sewage bypass would not affect the performance of six of the 12 STPs evaluated during this study. The performance of the other six STPs would be affected but the extent of the impact cannot be estimated due to the lack of information regarding the frequency, duration and magnitude of bypass events at these plants.

- Ten of the 12 STPs should be capable of achieving effluent nitrogen limits of 8 mg/L NH_3-N and/or 10 mg/L TKN without significant capital cost upgrading. If the costs of upgrading these 12 STPs is representative, the order-of-magnitude costs of achieving this effluent nitrogen limit province-wide in secondary treatment facilities is approximately $100 million.

- Seven of the 12 STPs should be capable of achieving effluent nitrogen limits of 3 mg/L NH_3-N and/or 5 mg/L TKN without major capital cost upgrading. Order-of-magnitude costs of achieving this effluent nitrogen limit province-wide in secondary treatment facilities based on costs incurred at these 12 STPs are estimated at $860 million.

- STPs which achieve partial nitrification may have difficulty complying with effluent requirements based on total BOD_5 because of the nitrogenous oxygen demand exerted in the uninhibited BOD_5 test.

6.0 RECOMMENDATIONS

Specific recommendations to address the factors identified as significant contributors to poor STP performance were developed and are presented in the subsections below. In addition, more generic recommendations regarding necessary follow-up to this study are presented.

6.1 SLUDGE MANAGEMENT LIMITATIONS

- Adequate storage should be provided to support the final disposal method in use at each STP. In the case of facilities depending on agricultural utilization, this may amount to up to six months of sludge storage capacity. Adequate approved land must also be available to support the utilization program.
- Contingency plans should be developed outlining the steps which will be taken in the event that inclement weather or sludge quality precludes disposal of sludges for a period beyond the available storage capacity.
- Consideration should be given to regionalizing smaller STPs into a common sludge utilization program where it is practical.
- More expedient approval of land for sludge application would reduce instances where inadequate land is available for sludge disposal.
- Improved record-keeping and reporting of sludge wastage and disposal is required to assess the adequacy of sludge disposal at STPs. Typical ranges of sludge generation for various types of treatment facilities in Ontario should be prepared for comparative purposes.

6.2 OPERATOR TRAINING

- Current methods of delivering training to operating staff need to be assessed and consideration given to training staff at the facilities which they are responsible for operating.
- Training courses aimed at improving plant management staff's leadership, communication and motivational skills should be developed. Management staff should be encouraged to involve operators in developing site-specific process monitoring programs and operating strategies.
- O&M manuals emphasizing process control testing and operations specific to the facility should be prepared at all STPs. Operating staff should participate in the preparation of these manuals.
- Programs should be developed to provide municipal STP operators access to technical process specialists where warranted.

6.3 ADMINISTRATIVE SUPPORT

- Certificates of Approval with specific effluent limits should be issued and current enforcement programs enhanced to raise awareness and provide incentive to STP operating authorities to improve plant performance.

- A mechanism to avoid unnecessary capital expenditure on plant expansion as a means to improve plant performance is also needed. The approaches used in U.S. jurisdictions such as Wisconsin and New York need to be evaluated and considered for application in Ontario.

6.4 HYDRAULIC LOADING AND EXTRANEOUS FLOW

- Sewage Collection System Needs Studies and sewer rehabilitation programs should continue to be emphasized to control extraneous flows into the treatment plant. These studies need to include a cost-benefit analysis of the relative merits of sewer system rehabilitation compared to sewage treatment expansion to handle the extraneous flow component. Municipalities and consulting engineers should be encouraged to integrate "NEEDS" and "Environmental Assessment (EA)" studies in managing I/I problems. The integrated approach will allow an optimal combination of sewer rehabilitation, storage and treatment to address extraneous flow problems.

- Less capital intensive methods of improving secondary clarifier performance such as baffling, polymer addition, step-feeding, flow equalization, provision of selector zones or varying sludge recycle should be evaluated to mitigate hydraulic load problems prior to a general plant expansion.

- On/off raw sewage lift pumps should be sized to be compatible with downstream unit processes such as clarifiers which are sensitive to hydraulic disturbances. Alternately, variable capacity pumps should be provided.

6.5 INDUSTRIAL LOADING

- The MISA Sewer Use Control Program should ensure that industrial discharges of conventional contaminants such as BOD_5 and TSS to municipal STPs do not impair the performance of the facility in terms of BOD_5 and TSS removal efficiency.

6.6 OXYGEN TRANSFER

- More frequent monitoring of aeration basin DO concentrations should be done so that the oxygen supply can be adjusted to meet the demand.
- In smaller facilities where a common air supply is used for the aeration basin, aerated sludge holding tank, grit removal, return sludge and waste sludge functions, separating the air supply and providing airflow measurement and control should be considered so that operating staff can adjust airflow rates for critical functions.

6.7 INSTRUMENTATION AND CONTROL

- Instrumentation to measure and provide positive control of return sludge and waste sludge rates should be included in all facilities and the operators trained in the proper use of this and other I&C equipment in their plant.
- Flexibility of plant operation along with adequate instrumentation to measure key process variables is critical for effective plant operation. These items should not eliminated from a plant design in a effort to reduce the capital cost of the facility.

6.8 OTHER RECOMMENDATIONS

- The benefits of an integrated STP optimization approach which addresses all factors limiting plant performance should be demonstrated at a representative number of the facilities which were included in this phase of the project.
- A Best Management Practices Guidance Manual should be developed. The manual should recommend appropriate levels of staffing, instrumentation and process monitoring for various sizes and types of STPs.
- More detailed information regarding the frequency, duration and magnitude of raw sewage bypassing at Ontario STPs is needed before the effects of limiting bypassing on plant performance and the costs of mitigating the effects of bypass flows can be estimated.
- The effect of residual ammonia concentrations in the effluents from STPs which partial nitrify on the measured total BOD_5 concentration needs to be considered when effluent requirements are formulated under the MISA program.

REFERENCES

1. Water Resources Branch, Ontario Ministry of the Environment, "Report on the 1989 Discharges from Sewage Treatment Plants in Ontario", June 1991.

2. Gray, A.C. Jr., P.E. Paul and H.D. Roberts, "Evaluation of Operation and Maintenance Factors Limiting Biological Wastewater Treatment Plant Performance", EPA-600/2-79-078, July 1979.

3. Hegg, B.A., K.L. Rakness and J.R. Schultz, "Evaluation of Operation and Maintenance Factors Limiting Municipal Wastewater Treatment Plant Performance", EPA-600/2-79-034, June 1979.

4. Hegg, B.A., K.L. Rakness, J.R. Schultz and L.D. DeMers, "Evaluation of Operation and Maintenance Factors Limiting Municipal Wastewater Treatment Plant Performance, Phase II", EPA-600/2-80-129, August 1980.

5. 1984 National Municipal Policy, Federal Register, January 30, 1984.

6. U.S.EPA, "Handbook - Retrofitting POTWs", EPA/625/6-89/020, July 1989.

7. Hegg, B.A., K.L. Rakness and J.R. Schultz, "A Demonstrated Approach for Improving Performance and Reliability of Biological Wastewater Treatment Plants", EPA-600/2-79-035, 1979.

8. Ontario Ministry of the Environment and Environment Canada, "Report on the Comprehensive Performance Evaluation (CPE) Technique for Assessing Ontario Municipal Sewage Treatment Plants", In Press.

9. Canviro Consultants Ltd., "Phosphorus Removal Efficiency Upgrading at Municipal Treatment Plants in the Great Lakes Basin, Phase 1 - Historic Review", Report prepared for the Ontario Ministry of the Environment ISBN 0-7729-3402-9, February 1988.

10. Canviro Consultants Ltd., "Phosphorus Removal Efficiency Upgrading at Municipal Wastewater Treatment Plants in the Great Lakes Basin, Phase 2 - Sampling Program", Report prepared for the Ontario Ministry of the Environment ISBN 0-7729-3403-7, February 1988.

11. Canviro Consultants Ltd., "Phosphorus Removal Efficiency Upgrading at Municipal Wastewater Treatment Plants in the Great Lakes Basin, Phase 3 - Performance Improvements", Report prepared for the Ontario Ministry of the Environment ISBN 0-7729-3404-5, February 1988.

12. Canviro Consultants Ltd., "Phosphorus Removal Efficiency Upgrading at Municipal Wastewater Treatment Plants in the Great Lakes Basin, Summary Report", Report prepared for the Ontario Ministry of the Environment ISBN 0-7729-3401-0, February 1988.

13. Ontario Ministry of the Environment, "Final Report of the Issue Resolution Committee on Monitoring Data Analysis", 1991.

14. Canviro Consultants Ltd., "Final Report on Assessment of Alternatives for the Crystal Beach WPCP", Report prepared for the Regional Municipality of Niagara, February 1988.

15. Canviro Consultants Ltd., "Optimization and Upgrading of the Belleville WPCP", Report prepared for the Ontario Ministry of the Environment, October 1988.

16. Canviro Consultants Ltd., "Evaluation and Correction of Design and Operating Deficiencies at the Cambridge (Hespeler) Wastewater Treatment Plant", Report prepared for the Regional Municipality of Waterloo, July 1986.

17. CH_2M Hill Engineering Ltd. and Senes Consultants Limited, "Environmental Audit of the Highland Creek Treatment Plant", Report prepared for the Municipality of Metropolitan Toronto, October 1989.

18. CH_2M Hill Engineering Ltd., "Final Report Process Studies at Corbett Creek WPCP", Report prepared for the Regional Municipality of Durham, March 1990.

19. CH_2M Hill Engineering Ltd., "Final Report Process Studies at Duffin Creek WPCP", Report prepared for the Regional Municipality of Durham, March 1990.

20. CH_2M Hill Engineering Ltd., "Operational Audit of the Regional Municipality of Halton's Burlington Skyway Water Pollution Control Plant", Report prepared for the Regional Municipality of Halton, March 1991.

21. Ontario Ministry of the Environment, "Guidelines for the Design of Water Treatment Plants and Sewage Treatment Plants", April 1982.

22. Joint Committee of the American Society of Civil Engineers and the Water Pollution Control Federation, "Wastewater Treatment Plant Design", ASCE - Manuals and Reports on Engineering Practice - No. 36, 1977.

23. Water Pollution Control Federation, "Clarifier Design", Manual of Practice No. FD-8, 1985.

24. U.S. Environmental Protection Agency, "Process Design Manual for Suspended Solids Removal", EPA-625/1-75-003a, January 1975.

25. U.S. Environmental Protection Agency, "Process Design Manual Wastewater Treatment Facilities for Sewered Small Communities", EPA-625/1-77-009, October 1977.

26. U.S. Environmental Protection Agency, "Handbook for Identification and Correction of Typical Design Deficiencies at Municipal Wastewater Treatment Facilities", EPA-625/6-82-007, April 1982.

27. Great Lakes - Upper Mississippi River Board of State Sanitary Engineers, "Recommended Standards for Sewage Works", Health Education Service, Albany, New York, 1973.

28. Water Pollution Control Federation, "Anaerobic Sludge Digestion", WPCF Manual of Practice No. 16, 1968.

29. Water Pollution Control Federation, "Sludge Thickening", Manual of Practice No. FD-1, 1980.

30. U.S. Environmental Protection Agency, "Operation Manual-Sludge Handling and Conditioning", EPA-430/9-78-002, February 1978.

31. U.S. Environmental Protection Agency, "Process Design Manual for Sludge Treatment and Disposal", EPA-625/1-79-011, September 1979.

32. Speirs, G.W. and J.P. Stephenson, "Operational Audit Assists Plant Selection for Demonstration of Energy Savings and Improved Control", in Proceedings of the 4th IAWPRC Workshop on Instrumentation and Control of Water and Wastewater Treatment and Transport Systems, Houston, 27 April - 4 May 1985.

33. Stephenson, J.P., S.G. Nutt and G.W. Speirs, "On-line Instrument and Microprocessor Based Audit of Activated Sludge Systems", in Proceedings of the ISA 87, International Conference and Exhibit, Anaheim, California, October 4 - 8, 1987.

34. Stephenson, J.P., G.W. Speirs and S.G. Nutt, "The Wastewater Treatment Plant Process Audit - A Performance Appraisal and Plant Assessment Methodology", presented at the 60th Annual Conference of the Water Pollution Control Federation, Philadelphia, Pa., October 1987.

REFERENCES (cont'd)

35. Water Pollution Control Federation, "Operation of Municipal Wastewater Treatment Plants", Manual of Practice No. 11 - Volume I, II and III, 1990.

36. Water Pollution Control Federation, "Operation of Extended Aeration Package Plants", Manual of Practice No. OM-7, Operations and Maintenance, 1985.

37. U.S. Environmental Protection Agency, "Field Manual for Performance Evaluation and Troubleshooting at Municipal Wastewater Treatment Facilities", EPA-430/9-78-001, January 1978.

38. CH_2M Hill Engineering Ltd., "Estimating Staffing for Municipal Wastewater Treatment Facilities", March 1973.

39. Dept. of Ind. Eng. and Eng. Res. Inst., Iowa State University, "Estimating Staff and Cost Factors for Small Wastewater Treatment Plants Less Than 1 MGD, Part I, Staffing Guidelines for Conventional Municipal Wastewater Treatment Plants Less Than 1 MGD", June 1973.

40. Environment Canada, "Manual for Land Application of Treated Municipal Wastewater and Sludge", EPS-6-EP-84-1, March 1984.

41. Environment Canada, "Identification of Problem Areas in Water Pollution Control Plants", Canada-Ontario Agreement Research Report No. 15, 1976.

42. Romano, L., City of Windsor, Personal Communication, 1990.

43. Thompson D.J., J.P. Bell and J. Kemp, "The Feasibility of Implementing Step Feed Control of Storm Flow at Selected Water Pollution Control Plants: Phase I - Preliminary Investigation, February 1991.

44. Chapman, D., Wastewater Technology Centre, Personal Communication, 1991.

45. Environment Ontario, "MISA - Controlling Industrial Discharges to Sewers", ISBN 0-7729-4426-1, March 1989.

46. Pickett, R., Metropolitan Works Department, Municipality of Metropolitan Toronto, Personal Communication, 1991.

47. Schuk, W.W., W.W. Schuk Inc., Personal Communication, 1992.

GLOSSARY

BOD_5	biochemical oxygen demand (5-day)
d	day
DO	dissolved oxygen
F/M	food to microorganism ratio
g	gram
h	hour
ha	hectare
HRT	hydraulic retention time
I&C	instrumentation and control
I/I	infiltration/inflow
kg	kilogram
kW	kilowatt
L	litre
m	metre
m^3/d	cubic metres per day
mg	milligram
MIGPD	millions of Imperial gallons per day
MISA	Municipal-Industrial Strategy for Abatement
MLSS	mixed liquor suspended solids
MLVSS	mixed liquor volatile suspended solids
MOE	Ministry of the Environment
NH_3-N	ammonia nitrogen
NO_2-N	nitrite nitrogen
NO_3-N	nitrate nitrogen
O_2	oxygen
O&M	operations and maintenance
RAS	return activated sludge
s	second
SLR	surface loading rate
SOR	surface overflow rate
SRT	solids retention time
SS	suspended solids
STP	sewage treatment plant
SVI	sludge volume index
TKN	total Kjeldahl nitrogen
TP	total phosphorus
TSS	total suspended solids
UMIS	Utility Monitoring Information System
VSS	volatile suspended solids
WAS	waste activated sludge
WPCP	Water Pollution Control Plant
WTP	water treatment plant

APPENDIX 1

STATE OF WISCONSIN'S
COMPLIANCE MAINTENANCE PROGRAM

Appendix 1

State of Wisconsin's
Compliance Maintenance Program

Introduction

The U.S. Environmental Protection Agency is promoting the development of municipal water pollution prevention programs. These programs, to be administered by the states, require that water pollution control plants (WPCPs) be assessed on a regular basis to determine their ability to meet current and future requirements. The objective is to identify emerging problems and implement appropriate preventative measures.

Wisconsin has implemented the first municipal water pollution prevention program, known as the Compliance Maintenance (CM) Program. The CM Program was developed over two years with participation from municipal government officials and WPCP operators. The objective of the program is to maximize the life of the state's 671 WPCPs, constructed at an estimated cost of $2.5 billion ($U.S.)(ICF, 1991). The program is based on the following principles:

- adequate treatment plant O&M,
- sound fiscal management,
- evaluation of treatment capacity as design life approaches,
- upgrading or expansions before compliance violations occur,
- facility maintenance treated like other public sector utilities.

This appendix provides a brief summary of Wisconsin's Compliance Maintenance Program. Additional details can be found in "Assessment of Wisconsin's Compliance Maintenance Program"(1).

Program Description

The main tool of Wisconsin's Compliance Maintenance Program is a special reporting form which is filled out by WPCP operators annually. An overall score for the facility is generated by the operator based on a point system specified in the form. The higher the overall score, the less likely the facility will be able to maintain compliance.

The completed form is reviewed by the municipality's governing body with the WPCP operator and a resolution adopted indicating acceptance of the report and any actions to be implemented. The completed form and resolution are forwarded to the District Office of Wisconsin Department of Natural Resources (WDNR) where a response letter by the Department is prepared. Included in the response are recommendations for addressing any identified problems. If the facility has a low score, any actions to correct identified problems are voluntary. If the score is intermediate, the WDNR notifies the municipality that an operational needs review is recommended. This review evaluates the treatment system's ability to maintain effluent limits over the next five years. If the score is high, the WDNR requires the municipality to complete an operational needs review within a specified period. Report scores are compiled by the WDNR's Central Office for all municipal WPCPs in the state.

Compliance Maintenance Annual Report

The Compliance Maintenance Annual Report form contains both objective and subjective components. In the objective section, a total score of 400 points is distributed as follows:

- flow and BOD loadings (0-80 points),
- effluent quality/plant performance (0-100 points),
- age of facility (0-40 points),
- bypass/overflow occurrence (0-50 points),
- sludge storage (0-50 points),
- sludge disposal (0-50 points),
- community growth (0-20 points),
- operator education and certification (0-10 points).

Additional information is requested concerning the financial status of the facility. The subjective portion of the form requests that the operator describe conditions in the treatment plant and sewer system. The completed report provides a snapshot of the condition of the WPCP on an annual basis.

Points totals are treated as follows:

0-70: Voluntary Range,
71-120: Departmental Recommendation
121-400: Department Action.

Financial Incentives

Prior to the implementation of the Compliance Maintenance Program, Wisconsin provided assistance to WPCPs to bring them into compliance. Following the start of the Program, financial assistance in the form of loans and grants is only provided to a municipality if their WPCP is in compliance. No financial assistance is provided if the WPCP is noncomplying. Municipalities therefore have a substantial incentive for keeping their WPCPs in compliance.

Program Benefits

Major benefits of the Compliance Maintenance Program include improved compliance, increased communication, and more effective planning. The number of WPCPs which were out of compliance decreased from 15-20% to 2% following inception of the Program. Communication is increased because operators are required to summarize the needs of their facility and communicate them to their municipal governing agency. The municipal governing agency is held accountable for the compliance status of the municipality's WPCP. The report also improves the public's understanding of the need to maintain and upgrade WPCPs because technical data is presented in a simplified manner. The state uses the Compliance Maintenance Annual Reports to plan operator training and prioritize site visits from WDNR engineers.

References

1. ICF Incorporated, "Assessment of Wisconsin's Compliance Maintenance Program", prepared for the Office of Wastewater, Enforcement and Compliance (U.S. Environmental Protection Agency) and Wisconsin Department of Natural Resources, Oct. 3, 1991.

APPENDIX 2

STATE OF NEW YORK'S
INTEGRATED COMPLIANCE STRATEGY SYSTEM

Appendix 2

State of New York's Integrated Compliance Strategy System

Introduction

The Federal Clean Water Act originally established July 1977 as the deadline for municipal water pollution control plants (WPCPs) to comply with permit requirements. This date was later amended to July 1988 to allow additional time for some WPCPs to achieve compliance.

In 1984 the U.S. Environmental Protection Agency (EPA) signed the National Municipal Policy (NMP), which states that the goal of the EPA is to achieve compliance with the act as soon as possible. Where necessary, enforceable schedules were established to ensure compliance with a specified time period.

The NMP identified three basic documents to be used in support of achieving compliance. These are (1) State strategies describing each individual state's plan to bring non-complying facilities into compliance, (2) Composite Correction Plans (CCP) to be developed by affected Municipalities which have constructed the necessary facilities but are not in compliance with effluent permits limits, (3) Municipal Compliance Plans (MCP) to be completed by Municipalities needing to construct a wastewater treatment facility to achieve compliance.

This appendix provides a brief summary of the New York State Integrated Compliance Strategy System. Additional details can be found in the "Annual Report of Wastewater Operator Training, Technical Assistance and Certification"(1)

Integrated Compliance Strategy System (ICSS)

In March 1984, the New York State strategy for implementing the NMP was accepted by the EPA. The ICSS is the Division of Water's coordinated process for responding to significant non-compliance. The most appropriate strategy for achieving compliance is developed through input from the Operations Assistance Section, Compliance Section (Enforcement), Source Surveillance Section (Monitoring), and Construction Management (Financing).

The system objectives are to:

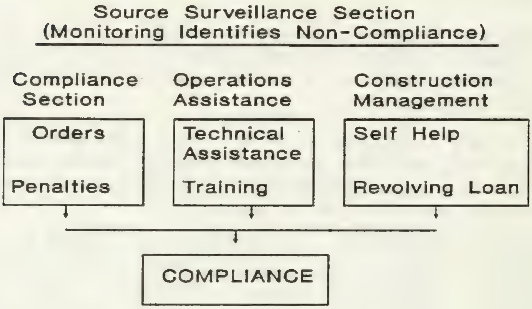
(1) Monitor the performance of all facilities.

(2) Identify facilities that are in significant non- compliance with permits.

(3) Develop a Department response to non-compliance, which utilizes the appropriate Departmental resources resulting in a comprehensive strategy aimed at re-establishing compliance.

(4) Implement the strategy.

Integrated Compliance Strategy System
Approach to Obtain Compliance



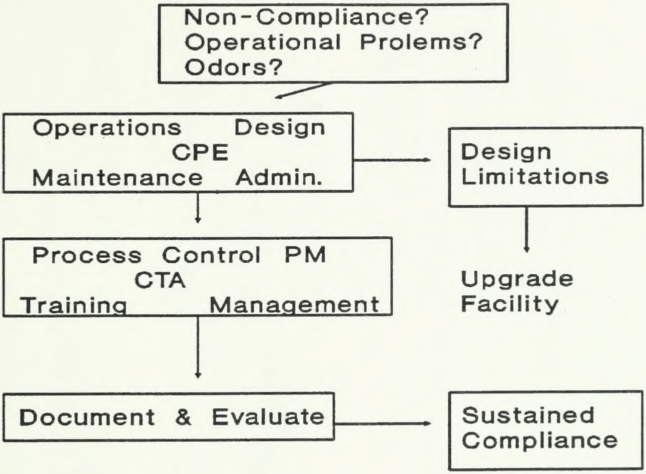
Composite Correction Program

Development of a CCP is mandatory where non-compliance is attributable to performance limiting factors other than those requiring significant construction (extending over one year or more), and which cannot be corrected in nine months or less. A CCP is likewise encouraged where problems are relatively complex, and where it is not clear whether construction will be a necessary part of the solution. In developing a CCP, assistance is available from the Bureau of Wastewater Facilities Operations. However, the development and implementation of a CCP is the responsibility of the Municipality.

A CCP must (1) identify factors that limit the performance of the wastewater treatment facility, (2) prioritize the factors in order of significance, (3) establish the corrective measures to be employed, (4) provide an implementation schedule for the measures selected, and (5) develop a monitoring program and provide adjustments where necessary, following data evaluation and interpretation.

Where a CCP identifies that a plant is mechanically capable and the major performance limiting factors are operational or administrative, the facility is considered a preferred technical assistance candidate. On-site technical assistance focuses on improving facility performance through custom training and operational guidance. This technical assistance is an effective response where the plant is within design capacity and the physical facilities are adequate. When technical assistance has been initiated, support from the Regional Water Quality Engineer in the form of potential enforcement or penalties helps to keep the assistance program on schedule.

Key Steps In On-Site Assistance



Evaluation and Documentation

On-going evaluation and documentation of the assistance program is crucial to determine the effectiveness or need for other corrective action. The main criteria for evaluating improved performance is improved compliance as measured by effluent quality.

Follow-Up

Monitoring the long term effectiveness of the assistance program is important to ensure sustained compliance. Follow up visits are planned 6-12 months after completion of the assistance program. Implementation of corrective plans are discussed and any problems are resolved. This follow-up also provides the opportunity to reinforce the importance of proper application of concepts and testing to achieve process control.

References

(1) "Annual Report of Wastewater Operator Training, Technical Assistance and Certification" FY 1990/91. Prepared by the Operations Assistance Section, Bureau of Wastewater Facilities Operations, Division of Water, NYSDEC, Albany, New York.